ECONOMIC GEOLOGY

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PREFACE

This work is based upon a series of lectures which the author has been compiling for more than twenty years. It treats only of the metallic ores in addition to the chapters on the origin of ore deposits. The metals are arranged, with the exception of the precious and rare metals, in the order of their group separation, and the chapters comprise the metals of the different groups. A final chapter gives the economic or statistical treatment.

It has seemed wise to the author to omit the references which are given to students for library or laboratory work, as these are best worked out by each teacher to meet his own views and the needs of his individual pupils. The author has in preparation also a companion book covering the non-metallics.

The author wishes to express his great indebtedness to Prof. T. C. Hopkins, Syracuse University, who has read both the manuscript and the galley proofs and offered many timely suggestions in the preparation of the book; to Prof. W. J. Miller, Hamilton College, who has read the manuscript entire; to the many professors of other universities who have read various chapters of the manuscript and heartily cooperated with the author in this work; to Prof. Heinrich Ries, Cornell University, not only for his "Economic Geology," but also for the use of many of his photographs to which credit is given in the text; to Thomas and MacAlister, authors of "The Geology of Ore Deposits"; to F. W. Clarke, Chief Chemist of the U. S. Geological Survey, "The Data of Geochemistry"; to Prof. J. F. Kemp, Columbia University, "Ore Deposits of the United States and Canada"; to Prof. J. C. Branner, Leland Stanford University, "Syllabus of Economic Geology"; to the authors of the Mineral Industry, its Statistics, Technology and Trade; to the compilers of the various volumes of the Mineral Resources; to the authors of all geological publications whose works have been consulted and embodied in part in this volume; to the Macmillan Company for their courtesy in loaning many cuts; to the *Engineering and Mining Journal* and the Canadian Geological Survey for the use of illustrations; and to the authors of all other cuts save the original drawings from whatsoever source they may have been derived.

CHARLES H. RICHARDSON.

SYRACUSE UNIVERSITY,
November, 1913.

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CHAPTER I

ORE DEPOSITS

INTRODUCTION

What constitutes an ore deposit? An ore deposit may be defined as a body of rock which contains metals or metallic compounds in sufficient quantity to allow the profitable extraction of some metallic content. A few of the metals occur in the native state. This is especially true of the precious metals: gold, silver and platinum. The most common occurrence of the commercial metals is that of the sulphides, oxides, hydrous oxides, carbonates, etc. Some mineral deposits which to-day do not fall within the definition of an ore deposit, may by subsequent concentration become sufficiently enriched to be of economic importance.

Associated with the metallic minerals are certain non-metallic minerals. The commonest of these is quartz, SiO_2; next in the order of importance is calcite, $CaCO_3$, then fluorite, CaF_2, barite, $BaSO_4$, and siderite, $FeCO_3$. Of less importance than the five minerals mentioned there appears as gangue minerals dolomite, rhodochrosite, feldspars, amphiboles, pyroxenes, etc. It often occurs that a large part of the vein consists of gangue and the economic product occupies the position of a thin seam within the vein-filling.

These gangue minerals are of lower specific gravity than the ores and may often be mechanically separated from them. Again they are so barren of metallic minerals as to permit separation through the hand sorting of the ore. The gangue is then transported to the dump, while the material containing the valuable metal is carried to the mill for treatment.

Primary Source of Ores.—The question naturally arises, what is the primary origin of the ores? Four principles are cited by C. R. Keyes, in his "Ultimate Source of Ores:" (1) Deposition from sea water. (2) Inclusions of metallic minerals as accessories in

the igneous rocks and the subsequent extraction, segregation and concentration of the ore materials through weathering processes. (3) Production of metalliferous bodies in connection with rock masses in a molten state, either through magmatic segregation or by the expulsion of the volatile compounds of the metals during the process of magma-cooling. (4) Derivation of metallic particles from extra-terrestrial sources, and their later segregation through the action of surface water.

Many early writers, including the eminent chemist Bischof, argued that sea water was the primitive source of the metallic salts in nature. They claimed that the metallic salts of the ocean were gathered into ore bodies where marine sediments were laid down. The idea has its foundation in the erroneous assumption that rock masses undergo no change.

The answer then to the query, what is the primary source of the ores, is the igneous rocks: Either the deep-seated masses upon which the earliest sedimentaries were deposited, or intrusives brought into the sedimentaries in a plastic or fluid condition.

A certain amount of volcanic water is intimately associated with the development and enrichment of some ore deposits Even granites at the time of their formation contain much water, which is liberated upon cooling, or when they are brought near the surface by faulting or erosion. The general effect of magmatic waters is reserved for discussion in the chapter on The Origin of Ore Deposits.

Third, the source from which the water derives the metals is the zone of fracture. The jointing of limestones, granites, and basalt is familiar. It must be along that line of fracture that the water seeps, yet there is a considerable amount of water filling the interstices of the rocks themselves. The water must gather up the material for transportation along these lines and deposit it again thus forming an ore body.

Fourth, the force which drives the water in its circulation is gravity. This is the recognized force that raises the water in the artesian well, that drives natural gas to the dome where it is found, and petroleum to the pool where it is collected.

Three courses have been advanced for the trend of solutions. (1) The theory of the descensionists. (2) The theory of the asscensionists. (3) The theory of the lateral secretionists.

The first theory that meteoric waters bring the minerals into solution and carry them to the lower depths has an extremely

limited, if indeed, any application, save in the secondary enrichment of ore bodies. The second theory is that the solutions rise and bring the materials for the ore body from the lower depths to the higher altitudes. If ore deposits are found in the sedimentary rocks as they sometimes are (with the exception of the lead and zinc deposits of Missouri), the minerals were associated with a great rock mass whose detritus furnished the material for the new geological formation. Again, the composition of the igneous rocks as analyzed by the chemists of the United States Geological Survey leads to the conclusion that the economic metals are present in them in minute quantities, yet sufficiently large, that by concentration they may become of economic importance. Illustration: gold, silver, copper, lead and zinc have been found in fresh igneous rocks.

The derivation of metallic particles from extra-terrestrial sources and their later segregation through the surface waters must also be considered as one of the possible sources of certain classes of ore deposits. This latter theory has thus far received too little attention.

Enrichment of Ore Bodies.—There are four postulates relating to the enrichment of ore deposits as follows: (1) Ore deposits are segregated by underground waters. (2) The circulating underground water is mainly of meteoric origin. (3) The source from which the water derives the metals is the zone of fracture. (4) The force which drives the water in its circulation is gravity.

The first postulate needs no comment. In the second the water may be of meteoric or volcanic origin. The waters effecting this enrichment are often meteoric and vadose for it is that body of moisture which falls on the surface of the earth that passes through the soil and along the joint planes and through the fissures toward the interior of the earth, and later has a tendency to appear again at the surface of the earth in seeps and fissure springs.

This may be effected by infiltration, by sublimation with steam, by sublimation with gas, or by igneous injection. The last two methods have a few good applications.

The theory of the lateral secretionist is that the material is picked up along the fracture planes and carried into the fissures by the waters percolating through the rocks at right angles to the fissure. These mineral-bearing waters often

come from a long distance and derive the dissolved minerals from a large amount of rock, but the precipitation occurs near the surface. Each of the above theories seems incomplete in itself. They supplement each other in general harmony with underground circulation. The largest ore deposits like the copper deposits of Michigan have sometimes been formed by a single ascending solution and subsequently enriched near the surface by descending solutions; and also both near the surface and at greater depths by lateral secreting solutions.

The Causes of Precipitation.—Some authors have attributed precipitation to diminishing temperature and pressure of rising solutions alone. This is insufficient. The precipitation is generally due to the mingling of different solutions in the trunk channels whereby new chemical compounds are produced. Whenever a neutral or slightly acid solution of a lead salt comes in contact with hydrogen sulphide the lead is precipitated as lead sulphide. The resulting mineral is galenite. Precipitation is also influenced by the character of the wall rock, by the infalling of fragments from the fissure walls and the presence of minerals already formed. Replacement is also not an infrequent method of forming an ore body.

There is a time-honored belief that ore bodies increase in richness with depth. This theory is absolutely untenable. Whether the ore body will increase with depth depends upon many factors; as the breadth of the fissure at the lower altitudes prior to the filling; the amount of concentration of the ore that has taken place at the point of the filling, and the amount of enrichment that may have occurred through faulting or the introduction of intrusive bodies.

If the upper unit of measurement is large and there is great irregularity in richness, the general trend is toward impoverishment with depth. This may arise from the combined efforts of descending and lateral secreting solutions upon deposits already formed by ascending currents in conjunction with the erosion of large masses of overlying strata. Occasionally where the surface unit is large, there is little decrease in width with descent. This is due to the fact that the ore resulted from a single enrichment by ascending waters.

Gossan.—The contents of the upper part of the original vein become oxidized in the zone of weathering, as shown in Fig. 1, and are either washed away in alluvial deposits or are carried

down by meteoric waters to be precipitated by the chemical action of the underlying sulphides, or the constituents of the wall rock, or the effect of ascending solutions.

The surface illustrations are represented in the phenomena, known as gossan, or the *eisener hut* of the German, or the *chapeau de fer* of the French. This is well illustrated in the case of copper mines where the sulphide of copper has been dissolved and oxidized to a sulphate and reprecipitated at lower altitudes enriching the zone. The contact between the oxidized and the unoxidized portions of the ore is the richest part of the entire vein. The iron sulphide becomes converted into an oxide or hydrous oxide, the reddish or yellowish-brown mineral so often seen at the

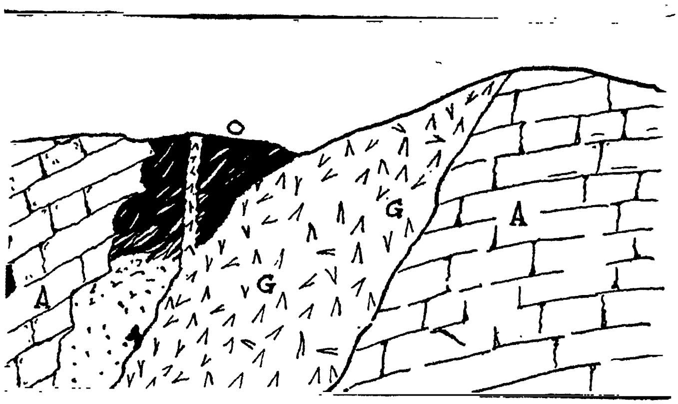


FIG. 1.—Superficial alteration of a contact deposit. *A*, limestone; *G*, granite; *O*, ore body.

surface. The result of this oxidation and the downward transference of the copper is the enrichment of the mineral vein for some distance. This enrichment varies with the depth and with the lowering of the water level, as erosion brings the upper portion of the vein within the zone of weathering. The downward transportation of metals or minerals already in lodes or pockets is the most potent factor determining the upper portion of the ore deposit, whose peculiar features are due to the nature of descending currents. It is not infrequent that ascending and descending waters work simultaneously. The result of this combined effort will give the richest deposits. In such cases a uniform law may be stated; first, an increase in value with depth of the zone of greatest enrichment; second, a

maximum in value where the combined efforts of ascending and descending solutions are the greatest; third, a decrease in value with the greater depths.

In the preceding discussion the enrichment of ore bodies has been effected mainly through waters of meteoric origin. It must not be forgotten that solutions which percolate through fissures and enrich ore bodies are often of magmatic origin, that is, they are derived directly from masses of igneous material.

In many cases these solutions have materially changed the

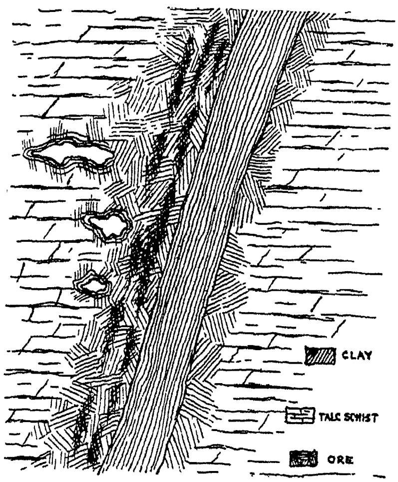


FIG. 2.—Section across a vein in the Hillside mine, Yavapai County, Arizona, showing the ore scattered through clay. (*After Rickard.*)

nature and value of mineral deposits previously existing within the fissure.

Mineral Springs.—Mineral springs as effecting ore deposits may be divided into three distinct classes.

(1) *Carbonated Waters.*—Water charged with carbon dioxide becomes a potent solvent for rock constituents. As the pressure is lessened this supersaturated solution is relieved of a part of its burden. The numerous varieties of travertine, as calcareous tufa and Mexican onyx, are illustrations of this type of material. Luray Caverns in Virginia, Mammoth Cave in Kentucky, and Limestone Cave in Austria illustrate the solvent power of carbonated waters.

(2) *Solfataras.*—This includes all waters in which sulphur is present either as a sulphide, as hydrogen sulphide or sulphur dioxide, and sulphurous acid. Hydrogen sulphide plays an important part in ascending solutions. Its source is in the decomposition of pyrite or gypsum. Its presence is the direct cause of a great number of minerals. The sulphide of the metals as a rule is the most important contributor to the source of the metal for commerce. Gold, iron and tin are the most noteworthy exceptions and others will be considered in the discussion of the respective metals.

(3) *Thermal Waters.*—These include hot springs and geysers. The temperature may arise from meteoric waters percolating through hot volcanic areas or magmatic waters slowly working their way toward the surface. More than one-half of the known elements have been found in solution in mineral waters. The elements were dissolved in the mineral waters themselves. They are found deposited in iron and manganese formations around mineral springs. They are dissolved and precipitated by the action of the mineral waters upon foreign bodies.

Origin of Cavities.—The form that ore bodies assume is such as to prove that they were often deposited in cavities and

FIG. 3.—Ideal section through a limestone region showing caves left by the removal of the rock.

fissures in the rocks. These cavities were formed by numerous causes.

(1) By acidulated waters dissolving the soluble constituents of rock masses as shown in Fig. 3, and by the mechanical action of water, that is, waters wearing away material by the force of impact thereby enlarging fissures already formed.

(2) Cavities are produced by dolomitization. Magnesium carbonate is readily taken into solution by carbonated waters under pressure. If in the downward transference of meteoric

waters charged with magnesium carbonate in solution a stratum of calcium carbonate should be encountered, a part of the calcium would be exchanged for the less soluble magnesium. In time there would occur a shrinkage of the rock mass amounting approximately to 12 per cent. Such a shrinkage would necessitate the shattering of the rock mass and the formation of cavities that might be subsequently filled with mineral matter.

(3) Cavities are caused by fracturing. Fracturing may be produced by a shrinkage as the direct result of the cooling. These fractures may be brought into the zone of vision through the erosion of large masses of superincumbent strata. If rocks are igneous in origin, these rocks must cool. If they cool, they must shrink. If they shrink, they must fracture.

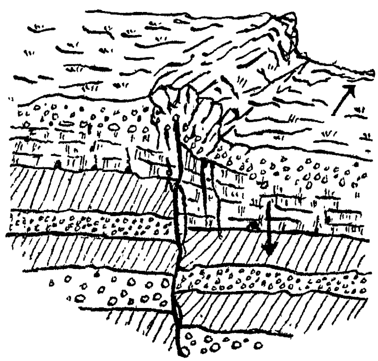


FIG. 4.—Section of a fault formed during a Japanese earthquake. (*After Koto.*)

(4) Cavities are produced in rock masses by earthquakes. These may arise through the intrusion of igneous dikes or by volcanic eruptions. (See Fig. 4.)

(5) Cavities may form in the sheared zone of intrusives. Massive diorites pass into diabases and then into hornblende schists or amphibolites. These amphibolites may metamorphose into serpentine. In the shearing and the serpentinization the crushed areas become favorable places for the formation of ore bodies.

(6) Cavities may be formed by the faulting of the strata without the formation of mountains. This may arise through lateral pressure. The displacement, however small it may be, affords a channel for the transference of solutions and the deposi-

tion of minerals whenever the conditions become most favorable.

(7) Cavities are formed in rock masses by the principles of isostacy and diastrophism in the maintenance of equal stress as evidenced in mountain making. Through diastrophism the strata become converted into a series of anticlines and synclines. Each type of folds often gives rise to fissures and a general shattering of the rock mass. While these two types of folds occasion the greatest disturbance, a pronounced effect is produced by the monocline in which there are two lines of yielding, one at the crest and the other at the base. These conditions produce a favorable environment for ore bodies.

Faults.—A fault is a fracture or disturbance of the strata

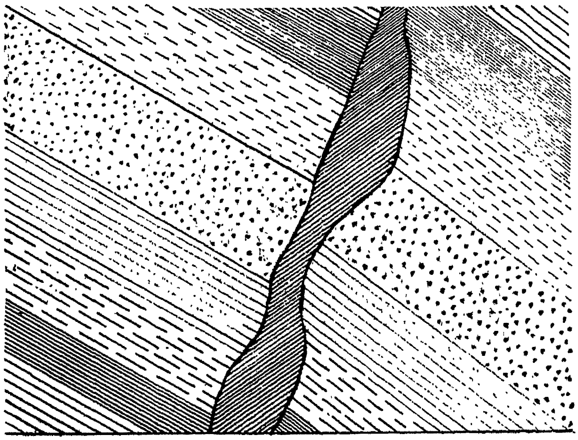


FIG. 5.—Ideal section showing a fracture filled along a fault plane.

breaking the continuity of the formations. (See Fig. 5.) As faults are usually inclined somewhat to the horizon there is both a vertical and a horizontal displacement of the strata, as shown in Fig. 6. The throw is the amount of the upward or the downward displacement of the strata. The dip is the inclination of the fault plane to the horizon. The hade is the inclination of the fault plane to the vertical. The strike is the direction of the outcrop of the fault plane at a horizontal surface. A fault produced by gravity is called a normal fault, and one produced by compression a thrust fault, yet it is possible in a few instances that normal faults have been produced by compression. It is of the utmost importance in mining to know

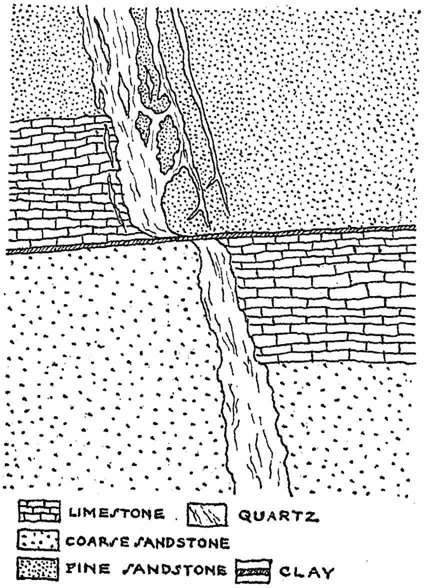


FIG. 6.—Section showing both vertical and horizontal faulting of a vein, Enterprise mine, Rico, Colorado. (*After Rickard.*)

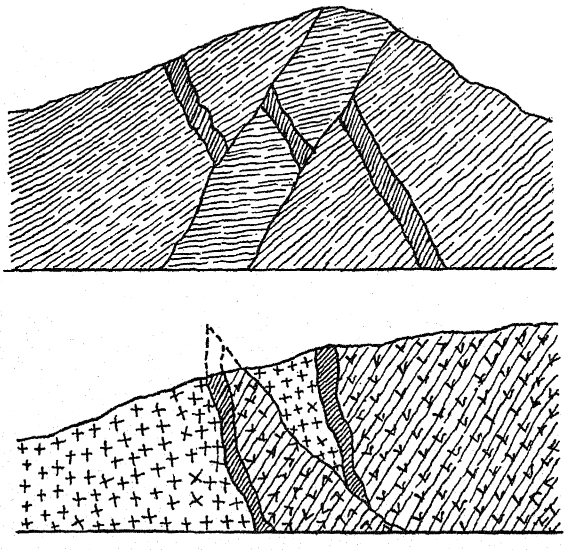


FIG. 7.—Illustrations of single veins repeated by faulting that left the different pieces parallel.

the system of faulting that prevails in a given district, in order that the ore body may be encountered again with the least possible expenditure of both time and money. (See Fig. 7.)

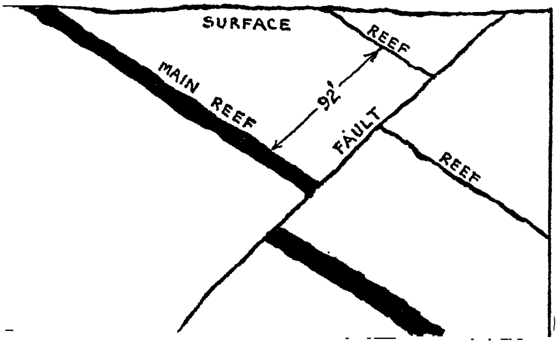


FIG. 8.—Section across the reefs of the Rand showing the faulting. (*After Hatch and Chalmers.*)

Schmidt's law is usually followed which is as follows: "If the fault dips or hades away from the workings, the continuation is down the hade. If it dips toward the workings, it should be followed upward" (Fig. 8).

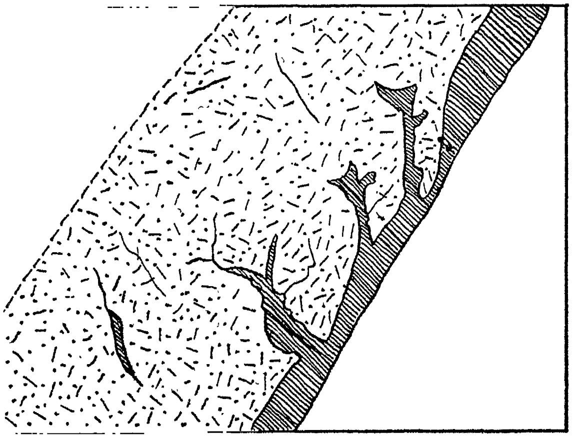


FIG. 9.—Quartz vein along the foot wall of a porphyry dike, with stringers running off into the porphyry. (*After Lindgren.*)

Veins.—The United States Supreme Court has defined a vein as any belt or zone of mineral rock lying within the boundaries

clearly defined as separating it from the surrounding rock. Mineral veins fall into three distinct classes:

(1) *Fissure Veins or True Veins of Fracture.*—A fissure is of indefinite length traversing strata independent of bedding, generally nearly vertical and filled with mineral matter. The fissure is not parallel to the bedding. The walls may or may not coincide, and are nearly parallel with each other. The fissure was in the rock prior to the filling. The fissure vein then is the filled fissure, which is of indefinite length. It is from the fissure veins that our largest supply of the precious metals comes. (See Fig. 9.)

(2) *Gash Veins.*—Gash veins are represented by a metalliferous deposit found only in limestones and confined to a single layer or formation. They are the most common in the bedding and the joint planes. (See Fig. 10.)

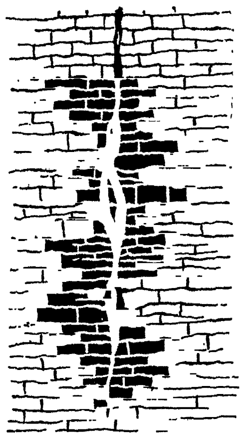


FIG. 10.—Gash vein in the magnesian limestone of Wisconsin. (*After Chamberlain.*)

(3) *Segregated Veins.*—These correspond to the planes of bedding or stratification and in many respects are not unlike true fissure veins or gash veins. These veins vary in thickness and direction. Their irregularities are many. They are often pinched out as by forcing the walls together, or by the expansion due to tension of the rock masses, or solution of the walls of the original channel. These veins also vary much in richness. The hanging wall is that part of the country rock lying geologically immediately above a vein or bed. The foot

wall is the lower boundary of a lode. The selvage is the zone of clay or decomposed rock, or both, separating the vein material from its walls (Fig. 11).

The Occurence of Metalliferous Veins.—(1) Metalliferous veins occur mostly in disturbed and highly metamorphosed regions. The tilting and the folding causes fissures that may be subsequently filled with mineral matter. Mineral veins therefore occur most frequently in mountainous regions or in the regions dis turbed by igneous activities. The lead deposits of Missouri are an exception to the rule for these occur in undisturbed and fossiliferous Paleozoic limestones.

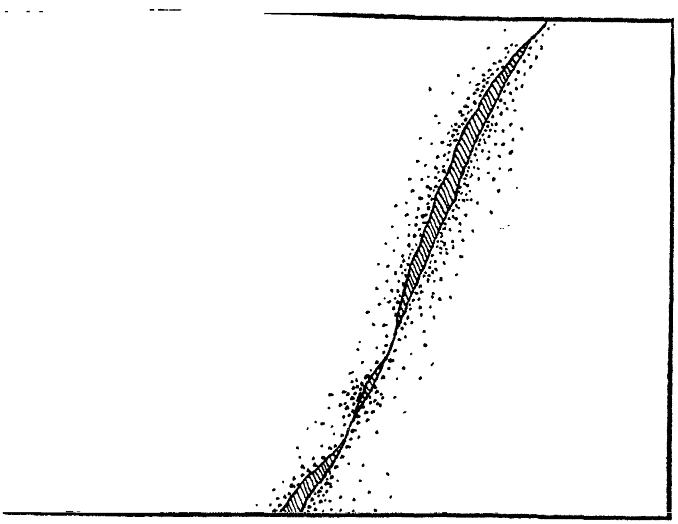


FIG. 11.—A vein with its ores extending into the altered country rock.

(2) These veins are more abundant in the older geological formations. There is no relation between the occurrence of mineral veins and age alone. The connection is with metamorphism, which is more common in the older terranes. In the Pacific coast belt metalliferous veins often occur in Jurassic, Cretaceous and Tertiary formations. But these terranes have been subjected to folding and metamorphism.

(3) Parallel veins usually have the same metallic content. (Veins at right angles may in some cases be exceptions.) The parallel fissures were formed by the same causes, at the same time and filled with similar material. Fissure veins not parallel with

each other (save perhaps at right angles) were formed at different times and filled under different conditions. The east and west veins at Cornwall, England, carry tin and copper and are pre-Triassic. The northeast and southeast veins are post-Triassic, but also contain tin and copper. The north and south veins are Cretaceous and contain lead and iron.

The Richness of Veins.—(1) If two mineral veins intersect each other one or both are generally richer at the point of intersection. This increased value may be due to the reaction of waters bearing different bases in solution in the two fissures.

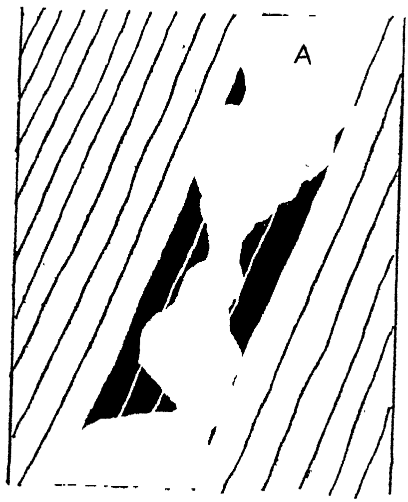


FIG. 12.—Section showing the form of the ore body in the, Victor, Smuggler Lee and Buena Vista miners, Cripple Creek district, Colorado. *A*, Ore. (*After Penrose.*)

(2) Mineral veins are likely to be richer near their intersection with either acid or basic intrusives. This is especially true in regions that have suffered much metamorphism. It shows the influence of heat upon the metallic contents of the veins.

(3) A change in the character of the county rock which a vein traverses may determine a change either in the contents or in the richness of the vein material. A vein may be well defined in the sedimentaries in close proximity to an acid or basic intrusive but upon invasion of the igneous rocks the vein is often subdivided into numerous branches.

Irregularities in Veins.—(1) Fissure veins are often irregular, as shown in Fig. 12. The vein often divides into numerous

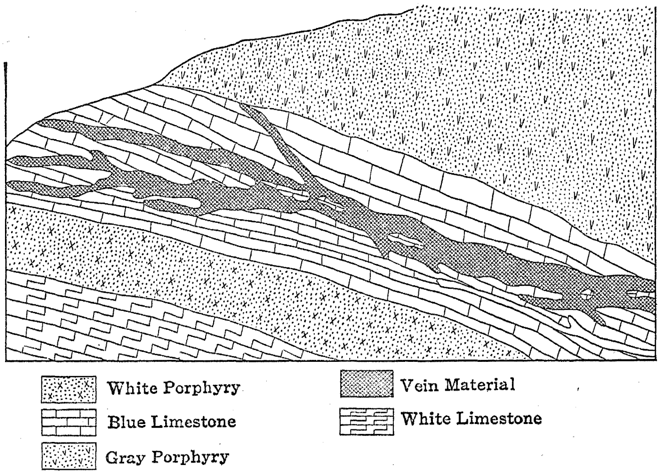


FIG. 13.—Section on the gold ore chute of Iron Hill, Leadville, Colorado. (*After Blow.*)

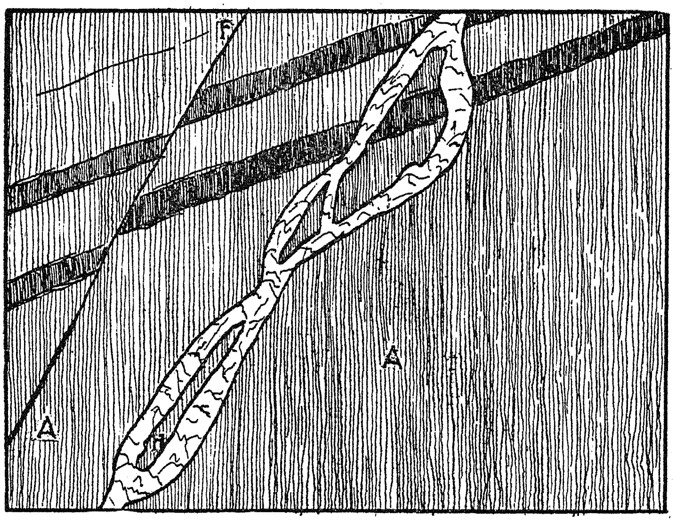


FIG. 14.—A troop of horses with the vein passing around it on both sides. *A*, Country rock; *H*, horse; *F*, fault.

branches. This is especially true as a vein passes from the sedimentaries into the associated intrusives (Fig. 13).

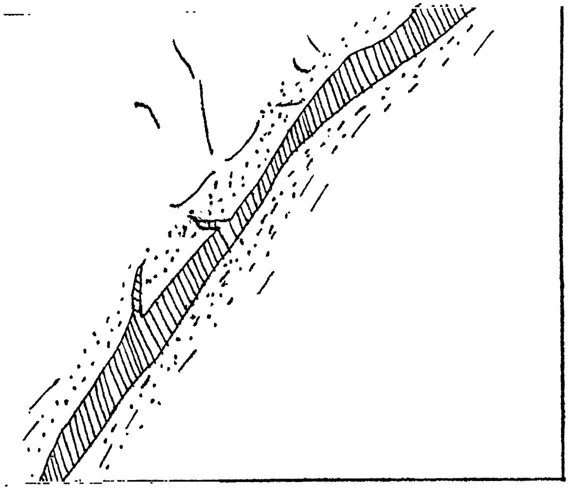


FIG. 15.—Ore bearing quartz vein, somewhat lens-shaped. The country rock is altered, but contains no ore. (*After Lindgren.*)

(2) Veins often dividing may come together as one vein and enclose a portion of the country rock. Such an enclosed portion is called a "horse." Several masses of rock may appear within

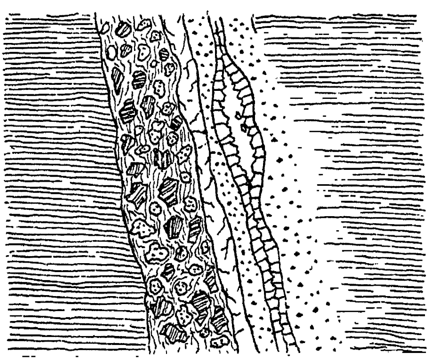


FIG. 16.—A vein brecciated on one side and banded on the other.

the vein and then they are called a "troop of horses," as shown in Fig. 14.

(3) Veins may pinch together by the creeping of the strata of the wall. In such cases the walls are mashed and the veins filled in part at least by the pressure of the superincumbent weight.

(4) Veins may widen out and rise to lens-shaped ore masses within the vein (Fig. 15).

(5) They may also be made irregular by repeated crustal movements, which break the rock into rubble-like material. The filling of these incipient fracture planes gives rise to the brecciated veins, as shown in Fig. 16.

(6) Irregularities are also formed by the solution of limestones by percolating waters, charged with carbon dioxide.

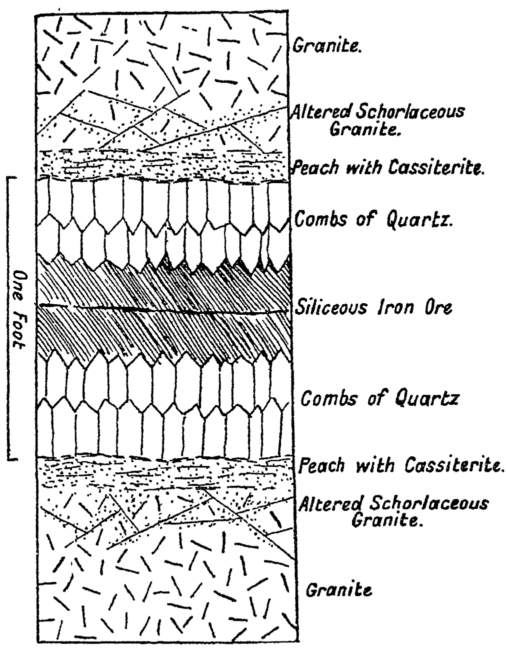


FIG. 17.—Structure of a lode at the Bellau mine, St. Just, Cornwall, England. *(After Thomas and MacAlister's Geology of Ore Deposits.)*

Ribbon Structure.—A banded or ribbon structure is not uncommon in the veins. In fact, according to LeConte, it is as common in veins as the columnar structures is in dikes. The layers upon the two sides usually correspond with each other in color or in composition, and, therefore, gives rise to a beautiful striped appearance. Sometimes these successive layers are of different

materials. Occasionally where the gangue is quartz the layers are of agate, save the center, which presents a comb-like structure of interlocking quartz crystals, as shown in Fig. 17. Sometimes there appears to have been successive openings and fillings of the fissure both with the gangues and the metallic minerals. This is considered by many geologists as conclusive proof of the filling of fissures from solutions.

Age of Veins.—The age of veins is determined by the manner of their intersection. The intersecting vein is always younger than the intersected. The geological period to which fissure veins belong must be determined by the fossil content of the associated terranes and by the stratigraphical position or the lithological similarity of the contiguous areas in which the fissures were formed. The filling of the fissure with gangue and metallic minerals is a slow, subsequent operation.

Classification of Ore Deposits.—The classification of ore deposits is a matter of convenience. It generally depends upon the purpose desired. They may be classified as to their mode of occurrence, as fissure, lens-shaped, bedded, etc. The following classification is based mainly upon use. Metals, precious and useful.

PRECIOUS.—Gold, silver, platinum, etc.

USEFUL.—Copper, iron, aluminum, zinc, and lead. *Fuels:* coal, petroleum, gas, naphtha, paraffine. *Lubricants:* graphite and oil. *Structural:* granite, limestone, sandstone, clay. *Ornamental:* phosphates, onyx, marble, amber. *Fertilizers:* limestone, marl, feldspars, phosphate. *Explosives:* diatomaceous earth. *Miscellaneous:* asbestos, paint.

They may be classified as to origin for the origin of economic products is as widly different as the products themselves. Prof. J. F. Kemp gives the following. terse order: Solution, igneous, suspension. Prof. Franz Prosepny gives them Idiogenous, that is contemporaneous, xenogenous, that is later than the rock. Prof. W. O. Crosby gives them Igneous, aqueo-igneous, aqueous.

The following classification has been arranged by W. H. Weed.

A. Igneous magmatic segregation.
  (a) Siliceous.
    1. Masses. Aplite masses. Ehrenberg, Shartash.
    2. Dikes. Beresite or aplite. Berezovsk.
    3. Quartz veins. Alaska, Randsburg, Black Hills, S.D

(b) Basic.
1. Peripheral masses. Copper, iron, nickel. Sudbury, Ontario.
2. Dikes. Titaniferous iron. Adirondacks and Wyoming.

B. 3. Igneous emanations. Deposits formed from gases above or near the critical point, *e g.*, 365° C. and 200 atmospheres for H_2O.
(a) Contact-metamorphic deposits.
1. Deposits confined to contact. Magnetite deposits (Hanover, New Mexico); chalcopyrite deposits, Kristiana type; gold ores, Bannock, Idaho, type.
2. Deposits impregnating and replacing beds of contact zone. Chalcopyrite deposits, pyrrhotite ores, magnetite ores, Canada type; gold tellurium ores, Elkhorn type; arsenopyrite ores, Similkameen type.

(b) Veins closely allied to magmatic and to Division D.
1. Cassiterite. Cornwall, Eng.
2. Tourmaline copper. Sonora, Mex.
3. Tourmaline gold. Helena, Montana; Minas Geraes, etc.
4. Augite copper, etc. Tuscany.

C. Fumarolic deposits.
(a) Metallic oxides, etc., in clefts in lava. No commercial importance. Copper, iron, etc.

D. Gas-aqueous or pneumato-hydato-genetic deposits, igneous emanations, or primitive water mingled with ground water.
(a) Filling deposits.
1. Fissure veins.
2. Impregnation of porous rock.
3. Cementation deposits of breccia.

(b) Replacement deposits.
1. Propylitic. Comstock, Nevada.
2. Sericitic, Kaolinic, calcitic, copper-silver, silver-lead. Clausthal, De Lamar, Idaho.
3. Silicic dolomitic, silver-lead. Aspen, Colorado.
4. Silicic calcitic. Cinnabar, California.
5. Sideritic silver-lead. Coeur d' Alene, Idaho; Slocan, B.C.; Wood River, Idaho.
6. Biotitic gold-copper. Rossland, B. C.

7. Fluoric gold tellurium. Cripple Creek, Colorado.
8. Zeolitic. Michigan copper ores.

STRUCTURE, TYPES OF THE CLASSIFICATION UNDER D

Fissure veins: San Juan, Colorado. *Volcanic stocks:* Nagyag and Cripple Creek. *Contact chimneys:* Judith. *Dike replacements and impregnations. Bedding or contact planes:* Mercur, Utah. *Axes of folds:* Synclinal basins, anticlinal saddles. Bendigo, Elkhorn.

E. Meteoric waters. (Surface derived.)

(a) Underground.

1. Veins. Wisconsin lead and zinc.
2. Replacements. Iron ores, Michigan. Lead, zinc, Mississippi Valley.
3. Residual. Gossan iron ores, manganese deposits. Virginia.

(b) Surficial.

1. Chemical. Bog iron ores, sinters. Some bedded iron ores, etc. Clinton ore, New York.
2. Mechanical. Gold and tin placers. California, Alaska.

F. Metamorphic deposits. Ores concentrated from older rocks by metamorphism, dynamo or regional.

What Constitutes a Mine?—(1) In the broadest sense a mine may be said to consist of a body of ore sufficiently large and rich to pay for the original purchase price of the property, all costs of mining, transportation, reduction plant, together with a large percentage of interest on the investment.

(2) In determining what constitutes a mine, it is necessary to consider each item of possible expense chargeable against the property, all physical and geological conditions, and such ore bodies as are developed, together with their bearing upon future ore bodies.

(3) The situation of property is exceedingly important. In this connection it becomes necessary to consider availability of water, for power, for the treatment of the ore, and for the removal of slimes; fuel as a source of heat, and as a source of power; and timber for the shafts and underground workings. It is necessary to consider the accessibility of property both

for the purpose of shipping supplies to the mines and marketing the ore or bullion; the question of dumping ground for the removal of waste; the position of the mill for the reduction of the ore, and position of the smelter for roasting the ore.

(4) The geological and physical problems in connection with determining the mine deal perhaps more with the future of the mine than with the actual cash value. In this connection one must consider not only the enclosing rocks, their resistance, definition and influence upon the mineralization, but must consider also the fissure deposits, if they are present, the faults, because in the majority of deposits the ore actually occurs in fissures and faults, or as fissure veins.

(5) Fissures and faults are additionally important because in many cases the continuity of the ore body must be determined. If faulted by intersecting fissures, this must be known and the consequence actually determined. It is a well-known fact that ore bodies are more often irregular in dip, strike, and formation than otherwise, the valuable portion of ore being controlled by some physical fact such as the intersection of the fissure with certain strata whose definition is known, intersection of fissure with the igneous rocks, and intersection of one fissure with another of different age. In a known district it is often possible by careful observation of these facts to calculate the exact position of valuable bodies. At Rico, Colorado, vertical veins intersect a zone of disturbance rich at the point of intersection. This has been proven generally true. Therefore, wherever vertical veins intersect a plane of disturbance, rich ore deposits are more likely to be encountered.

(6) Ore above or below water level is important on account of the method of treatment of the ore. Above water level there are frequently high-grade ores that can be quickly and cheaply reduced by a simple mill upon the ground, whereas below water level the milling process may be involved and expensive as it may be necessary to smelt the ores before reduction to the metallic state. These are very important items in the cost of reduction because of the additional expense required and the uncertain factor or the cost of reduction.

(7) It is also necessary to say whether the ores are primary or secondary in origin. Often there is a zone in the vein wherein are deposited, below water level, very rich bodies of ore which under normal conditions might reasonably be considered perma-

nent. Experience has shown that the deep ores even at a greatly increased expense of mining may be mined at a profit. Butte shows a zone of oxidation, a zone of sulphide enrichment, and a zone of permanent value in which the workings may be carried far below the surface and still obtain a definite value of metal. The Michigan copper mines and the gold mines on the west coast of British Columbia are examples of mines far below the surface carried on at a profit in the zone of permanent value, as the owners know exactly what to depend upon.

(8) The gross value of ore deposits is to be determined only by actual measurement of ores blocked out and the determination of the values by careful and conscientious sampling with sufficient precaution to assure the owner that the results are absolutely correct. It is a very easy matter to guess on the quantity of ore, but it would be an easy matter to make an overestimate or underestimate, for the only estimate that can receive credence is that based upon the ores actually blocked out. It is an easy matter in the sampling of ore chutes to arrive at an erroneous conclusion by a failure to sample the material of an entire vein and find where the value lies. If the purpose is to find out the value of an entire vein, samples are collected in different places; one from near the center, one near the hanging wall, one near the foot wall, one from across the top of the adit, one from the center, and one from near the bottom of the vein exposed. This method will not only tell where the pay streak lies, but also give the average of the entire face.

Ore bodies like other bodies have three dimensions and therefore can be blocked out only by actual development. These ore bodies must be cut and drifted upon at sufficient intervals to determine length, thickness, and form of the valuable chutes. The ore bodies may be divided into three classes:

(1) Ore actually in sight; (2) ore technically in sight; and (3) ore that under the conditions existing should be expected with proper development of the property.

(10) The next step is the determination of the method of mining and treatment of the ores for all time and whatever grade and kind, and to calculate the cost of converting ore into money. Here are 11 factors: Cost of mining, labor and supplies; cost of development, labor and supplies; cost of reduction; teaming; milling; loss in mill; loss in smelting; commission paid to smelter; cost of equipment of mine; cost of equipment of mill; cost of

equipment of smelter; cost of mill; cost of smelter; cost of managing smelter; cost of normal litigation that may arise from ore bodies coming from other than the ground in question; amount of interest on the money advanced for the original purchase and equipment at nominal rates; and, lastly, a large percentage of profit. To be a profitable mine the sum total of these costs must not exceed the gross value of the ore as calculated.

CHAPTER II

ORIGIN OF ORE DEPOSITS

Meteoric Origin.—In the light of the new planetesimal hypothesis of the earth's origin which has been so admirably worked out by Prof. T. C. Chamberlain there seems to be a continuous shower of extraterrestial material falling upon the surface of the earth. If this material strikes the land it mingles with the soil almost unnoticed. If it falls into the sea its high specific gravity carries the material to the ocean bottom where it is buried in the muds of the sea floor. If it falls upon the Arctic snow fields it enters into the ice and imparts the peculiar banded appearance characteristic of so many glaciers. Wherever this shower of meteoric dust may fall it becomes a possible source of ore deposits through segregation by vadose waters.

Number of Meteorites.—According to Prof. C. A. Young from 15,000,000 to 20,000,000 of meteorites enter the earth's atmosphere every 24 hours. One of the most noted of modern meteoric masses is that of the Canyon Diablo which fell in eastern Arizona. C. R. Keyes says that 20 miles east of the San Francisco mountains, in the midst of the vast level plain forming the general surface of the high plateau, is a low mound called Coon Butte. The center of this butte contains a crater-like depression about 1000 ft. across. In the vicinity of this hill such large amounts of meteoric iron have been found from time to time as to give rise to the theory that the crater was produced by an enormous meteorite striking the earth at this point. The impact caused the fragments to scatter in all directions. Meteorites are scattered over widespread areas rather than of local occurrence. The reports of the Challenger expedition cite a great abundance of chondrones of cosmic origin in the abyssmal deposits of the ocean. Nordenskjold cites the presence of minute, black, metallic particles in the Arctic snow fields. C. R. Keyes calls attention to hailstones containing fine metallic particles composed mainly of iron, nickel, cobalt and copper. He also cites the constant occurrence of meteorites

in the desert regions of the Mexican plateau situated many miles from the mountains and far away from igneous rocks.

Metallic Content of Meteorites.—Nearly all of the common metals have been found in meteorites and gold has been reported. As these particles reach the earth they mingle with the soil, oxidize in the presence of moisture, pass into solution and are transported to a deeper zone by the circulating ground waters. It is probable that a part at least of the widely diffused metallic content of sedimentary rocks is of meteoric origin, and that this extraterrestrial material is the primary source of many vadose ore deposits.

Segregation.—Many ore bodies are so intimately associated with masses of igneous rocks as to lead the observer to the

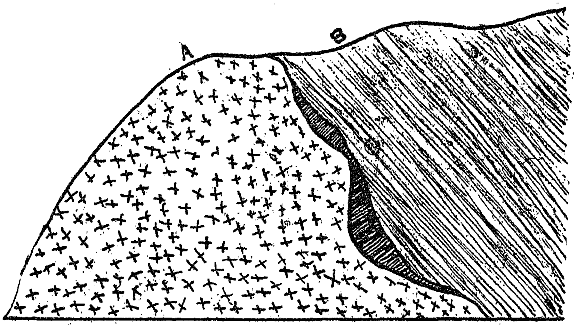


Fig. 18.—Example of a contact deposit between two different kinds of rock.

conclusion that such deposits resulted without doubt from the solidification of homogeneous or heterogeneous magmas through various causes of differentiation. Such deposits are so closely related petrographically to the rock masses as to lead to the conclusion that they form one heterogeneous complex. Magmas may be either homogeneous or heterogeneous. If the magma be homogeneous under the same conditions of temperature and pressure, there is uniform mobility in the various portions of the material. If the magma be heterogeneous then the more fluid portions may move readily toward the surface and the heavier and more basic material migrate toward the lower portion of such a magma. These magmas in which a perfect segregation may occur are deep-seated deposits brought into view through the erosion of a considerable amount of super-

incumbent strata. (See Fig. 18.) In the process of segregation of the ecomonic minerals three classes of ore deposits are formed: (1) The metals; (2) the oxides of the metals; and (3) the sulphides of the metals. Following the separation of the metallic content, the oxides and the sulphides of the metals, there appears the solidification of the ferro-magnesian minerals as the pyroxenes, the amphiboles, etc. After the solidification of the ferro-magnesian minerals comes a more acidic product as the feldspars and the last to separate is quartz. (See Fig. 19.) The causes of segregation are: (1) Fractional crystallization of the various

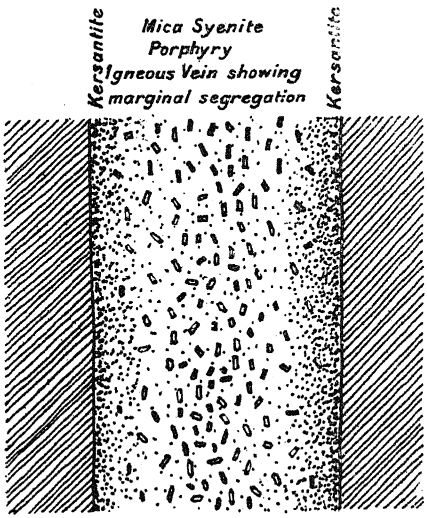


FIG. 19.—Vein of mica syenite-porphyry, showing marginal segregation of ferro-magnesian minerals and iron ores. (*After J. H. L. Vogt.*)

constituents of the magma. (2) The separation of the magma into two immiscible solutions, that is, solutions that will not mix, like water and oil. The completeness of the segregation may be determined by the rate of cooling of the magma as a whole. (3) The degree of viscosity. The viscosity will depend largely upon the chemical composition of the masses, varying with the relative amount of the ferro-magnesian and acidic minerals present. A segregation of the magma is not impossible before its appearance as an intrusive and this gives rise to ore bodies not unlike those segregating from homogeneous magmas, but the segregation is less complete.

We may consider one type in the segregation of ore bodies from an ultra-basic magma traversing the Appalachian belt from Alabama to Nova Scotia, appearing often in the Carolinas, Maryland, Pennsylvania, Vermont and Quebec in a belt of Paleozoic rocks pierced here and there by peridotite. The segregation in the Thetford and Black Lake districts, Quebec, is as follows, as shown in Fig. 20.

(1) The metals, chromium and iron, become oxidized and form lens-shaped masses of chromite and magnetite. There is a tendency for the chromite and magnetite to migrate toward the periphery of the mass and to appear often as lens-shaped ore bodies in the midst or in the border of the basic peridotite. The peridotite, rich in ferro magnesian minerals was the second

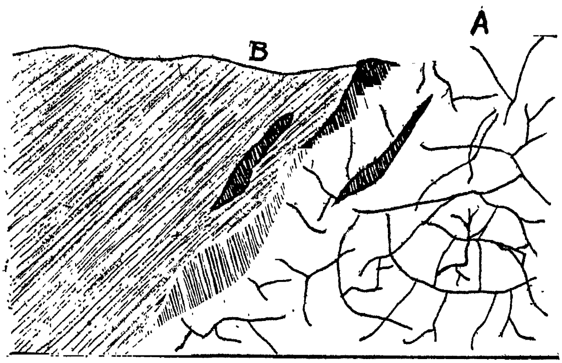


FIG. 20.—Section to illustrate the segregation of chromite and magnetite as lens-shaped ore bodies, Troy, Vermont. *A*, Perdotite; *B*, sericite schist.

mass to solidify. The peridotite consists almost entirely of the ferro magnesian mineral olivine.

If a difference existed in the constituents of the magma the pyroxenites would appear third in the process of solidification. The next product in the order of the solidification was acidic in character, light in color, of lower specific gravity, and the product a granite containing crystals of the potash feldspar, orthoclase, with granules of some ferro magnesian minerals, usually hornblende. The final product as a rock mass from solidification is the most acidic and ribbed by veins of aplite, in which the feldspars, micas and amphiboles are apparently absent. The final product through the differentiation of the ultra-basic magma gives free silica or quartz.

No scientist has ever worked more indefatigably in the products of magmatic segregation than J. H. L. Vogt. His classification gave us: (1) The segregation of the native metals; (2) the segregation of metallic oxides; and (3) the segregation of metallic sulphides. In the segregation of the metals, the precious metals, gold, silver, and platinum are formed.

(1) Silver, the least frequently occurring as an original mineral, is in such form and quantity as to lead to the conclusion that the metal followed the law of solidification of magmas from the basic to the acidic. Gold is found in considerable quantities in the basic rocks as diabases and diorites, and in such acidic rocks as the granites and syenites; examples of the latter are found in the pegmatites of Australia and Alaska. The platinum is a product of segregation from such ultra-basic rock masses as the peridotites and the modern form or appearance is as grains of platinum associated with the metamorphic products. In serpentine platinum is almost always associated with the segregation of chromite, although all chromite does not contain platinum. The most important segregation of metallic iron is manifested at Disco Island, on the western coast of Greenland where large masses having the appearance of meteoric iron have been discovered. It was not until the ore body was subsequently discovered in place that its true nature was known, viz., segregation from the basic intrusive basalt.

Cobalt and nickel are more or less common and wherever one is found the other is present. Perhaps in New Zealand is found the best illustration of ore bodies of cobalt and nickel segregating from a molten magma. This generally carries a certain percentage of iron, so it becomes an alloy of cobalt and iron.

(2) The second class of products segregating from molten magma is the metallic oxides. Types of chromite and magnetite are among the more important and more common. In many cases the titanium is so abundant in magnetite as to lead to the conclusion that the titanium oxide plays the rôle of an acid, and the iron that of the base. Illustrations are common in the formation of such ore bodies in the Adirondack Mountains in New York.

Another mineral sometimes segregating as an original mineral is cassiterite. In general, however, it is associated with pegmatite, an acid product in the solidification of some magma. In certain sections the character of the ore body is such as to

lead one to the conclusion that it is an original mineral. In the peridotite belt that stretches from Alabama to Nova Scotia, in North Carolina especially, corundum occurs in considerable abundance as an original mineral and emery is found in Massachusetts. The former has the formula Al_2O_3 and the latter contains hematite or magnetite intimately mixed with corundum. These original minerals, surpassed in hardness only by the diamond, are worthy of mention here for their use as abrasives.

(3) The third class as worked out by Vogt was that of the metallic sulphides. The segregation of metallic sulphides is characteristic of several types of igneous rocks as a result of differentiation either before or after intrusion. They are common

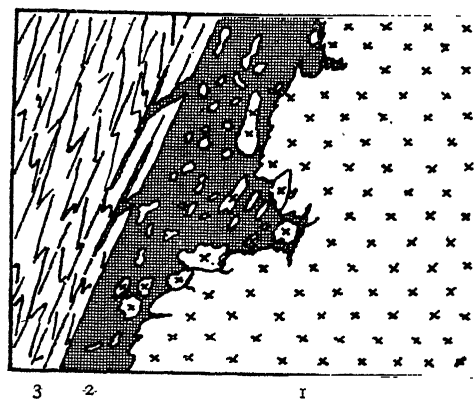


FIG. 21.—Section to illustrate the mode of occurrence of sulphidic segregations connected with norite intrusions. 1, Norite; 2, pyrite; 3, gneiss. (*After Thomas and MacAlister's Geology of Ore Deposits.*)

products of segregation from magmas rich in ferro magnesian minerals. The sulphides commonly occurring with igneous origin are copper, iron, cobalt and nickel. (See Fig. 21.) Associated with these are the arsenides of a few metals. These are less important and need not be further considered. The sulphide of copper most commonly segregating is chalcopyrite, $CuFeS_2$. Bornite and chalcocite may also occur as primary minerals.

Pneumatolysis.—Pneumatolysis demands the formation of ore bodies from both acid and basic intrusives through the agency of gases dissolved in the magmas. Because the gases were present at the time of the intrusion, they were under high pressure and above their critical temperature. The magmatic vapors and

steam are liberated during the consolidation of deep seated intrusives. The action takes place, not before consolidation begins, but during the process of consolidation and ceases altogether when solidification is complete. The vapors extract the metals from the cooling magma and deposit them as oxides and sulphides. Without pneumatolytic action the metals within the magma would remain as accessory minerals in the form of oxides, sulphides, or silicates, distributed through the rock. If these metals be present in sufficient quantities to become essential, they produce a massive segregation.

Pneumatolysis, therefore, is the process of extracting metals from deep seated magma by the agency of superheated gases. The ores are deposited in the fissures and joint planes, both in the igneous rocks and the adjacent metamorphic aureole. The character of the minerals in the lodes is determined by the type of magma from which they were derived. The classification of such ore deposits depends upon: (1) The nature of the rock giving rise to the ores. (2) The particular metals contained in the cooling magma. (3) The minerals associated with the ore bodies.

The gases are called carriers or mineralizers. Each magma has its own mineralizer, and whether the metals will be deposited as oxides or sulphides depends upon their chemical affinity and the presence or absence of sulphur. Tin, as will be shown later, is most abundant as the oxide even when sulphur is present in the magma, while lead is most abundant as the sulphide.

By the active magmatic gases the metalliferous minerals sparingly scattered through the cooling mass are withdrawn and more or less concentrated in the partially consolidated intrusive. The gases are then liberated and the ores concentrated in the lodes in which they are found, either in the intrusive or in the walls.

The third step is the liberation of thermal waters. The transition from concentration of minerals to liberation of thermal waters is gradual. The character of the ore bodies is determined by the nature of the fissures, joints, faults, breccias, bedding planes, or other cavities in which deposition has taken place. The form of the deposit is of the utmost importance to the miner. To the geologist the altered walls of the lode and the minerals of the lode determine the character of the magma from which the ore was derived. According to Thomas and MacAlister, the most typical pneumatolytic ores are cassiterite, wolframite, and scheelite, which may be associated with

sulphide of copper, iron, and arsenic, and less commonly ores of the other metals. (See Fig. 22.)

Cassiterite.—Lodes of tin are characterized by the presence of minerals bearing fluorine. This active element is able at high temperature to form a volatile compound with tin, which at a lower temperature is deposited as cassiterite according to the equation:

$$SnF_4+2H_2O=SnO_2+4HF.$$

Fluorine bearing minerals in the country rock owe their existence to the presence of free hydrofluoric acid. Boron, chlorine,

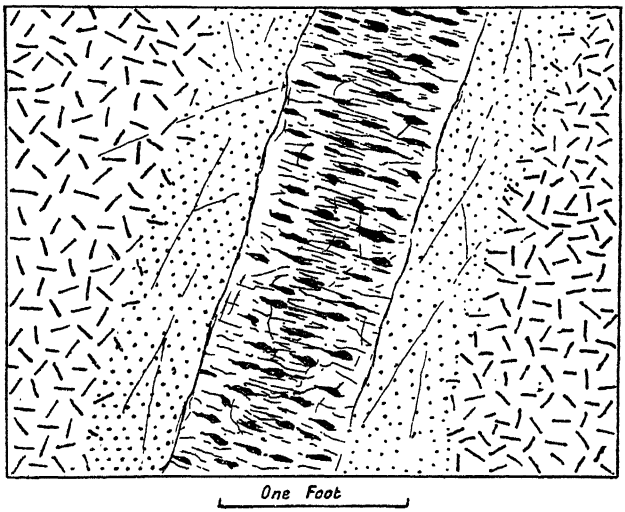


FIG. 22.—Tin lode at the Bunny Mine, St. Austell, Cornwall, England. (*After Thomas and MacAlister's Geology of Ore Deposits.*)

"The vein infilling is coarse cavernous quartz, with a distant resemblance to comby structure. It is a pegmatite vein containing cassiterite and wolframite, some feldspar in the vein is kaolinized and the adjacent granite is altered to greisen, A little fluorite and tourmaline are present."

carbon dioxide, and occasionally sulphur are present. These vapors also assist in the extraction of the metals from the magma. Fluorine also forms a volatile compound with silicon and the silica associated with tin veins may have been formed according to the equation:

$$SiF_4+2H_2O=SiO_2+4HF.$$

When the intruded rock is traversed by numerous joint planes, the vapors decompose its various constituents and readily form new minerals. If the country rock is not traversed by joints the process begins along planes of bedding or cleavage planes of minerals and the alteration is easily effected. Feldspars are kaonized and micas chloritized. Silicification of the country rock and greisenization also are not uncommon, but the character of the change depends upon the nature of the magmatic vapors.

Fluorine belongs to the earliest emanations but boron, carbon dioxide, and hydrogen sulphide may belong either to the early or later emanations.

Order of Deposition.—At Cornwall both the oxide of tin and the sulphide ores were simultaneously deposited. The presence of copper ores upon previously formed cassiterite leads to the conclusion that copper ores continued to be deposited after the deposition of tin had ceased. In other instances where tin and copper ores arrived simultaneously, cassiterite was deposited first.

Thomas and MacAlister give the order of deposition: (1) Cassiterite and wolframite, together with the sulphides of copper, iron and arsenic. (2) The sulphides of copper, iron and arsenic, associated with those of lead, silver and cobalt. (3) Silver sulphides and the oxides and carbonate of iron. (4) Nickel, antimony, and manganese minerals.

The intrusion came in as large batholites of granite cutting sedimentaries of Ordovician Age. At Central and East Cornwall they cut through Devonian rocks. The smaller batholites at Devonshire cut Devonian and Carboniferous strata. The ore is concentrated either in the periphery of the granite batholith or the metamorphic aureole.

The copper ores, containing chalcopyrite, chalcocite and bornite, where tin does not occur, are often of pneumatolytic origin. In Norway where copper lodes are associated with a greisenized granite, the ore is unquestionably formed under the principles of pneumatolysis.

At Copperfield, Strafford and Corinth, Vermont, the chalcopyrite, associated with tourmaline, occurs in saddle-shaped bodies in mica schist, or in chimneys at the contact of granite veins with mica schist. Pyrite and pyrrhotite are the associated sulphides. These sulphides were formed under pneumatolytic conditions.

Gold.—Gold is sometimes found in copper-tourmaline veins connected with intrusives. It is found principally in the quartz and the tourmaline lies near the walls of the vein. This is especially true in Thelemarken. In Ontario auriferous-tourmaline veins occur in which the walls of the country rock are well tourmalinized.

Titanite, rutile, anastase, and brookite are minerals often formed by pneumatolytic action associated with fluorine and boron-bearing minerals. Molybdenite is also found in quartz veins, pegmatites and granites in such manner as to show pneumatolytic action.

The Basic Intrusives.—Ore bodies associated with the basic intrusives, gabbros and diabases, are often markedly pneumatolytic, but not as common as in the granites, yet the process is the same. The principal agent or mineralizer is chlorine instead of fluorine or boron. Titanium would be extracted as the chloride and deposited as the oxide according to the equation:

$$TiCl_4+2H_2O=TiO_2+4HCl.$$

Iron is similarly extracted:

$$Fe_2Cl_6+3H_2O=Fe_2O_3+6HCl.$$

The reactions of phosphorus and lead are similar:

$$PCl_5+4H_2O=3HCl+H_3PO_4.$$
$$PbCl_2+H_2S=PbS+2HCl.$$

Fluorine and boron are rare in the basic, but common in the acid intrusives.

Hydatogenesis.—Hydatogenesis is the process by which ore bodies connected with the intrusives of basic and acidic magmas are formed outside the metamorphic aureole. In point of time they are generally post-pneumatolytic. If it happens to be contemporaneous then it must take place beyond the zone of metamorphism. If they appear in the aureole or in the igneous rock itself, they were not formed until solidification and metamorphism were complete. When the zone of metamorphism is free from minerals indicating mineralizers, the lode may be considered to belong to the hydatogenetic class. The ores are sulphides and oxides of the metals, the former predominating. To determine whether the ore body is of pneumatolytic or hydatogenetic origin, the geologist must look first to the nature

of the irruptive rock from which the minerals were derived; second, to the nature of the minerals in the lode, and third, to the character of the non-metalliferous minerals both in the lode and the metamorphic aureole. The magma may have been either basic or acid, deep-seated or superficial, irruptive or eruptive.

In the classification of hydatogenetic deposits, it is customary to select the most important economic mineral. Many deposits are catalogued as gold ores that are strictly pyritic lodes characterized by a small amount of gold.

Primary Gold Veins.—Hydatogenetic gold veins are associated

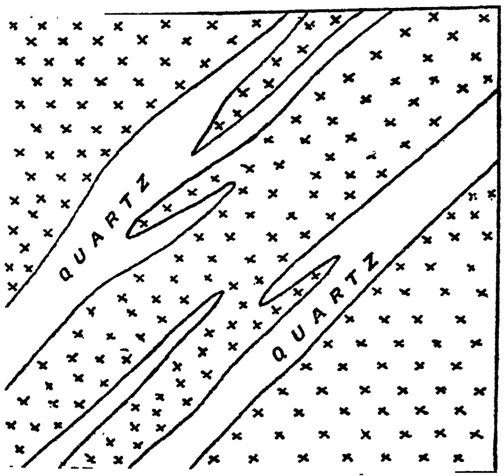


FIG. 23.—Section to illustrate the formation of auriferous quartz lenses in alaskite. (*After Thomas and MacAlister's Geology of Ore Deposits.*)

with granite, porphyry, andesite, trachyte and rhyolite. (See Fig. 23.) The chief gangue is quartz, but calcite, siderite and magnesite may be present with the quartz. Barite and fluorite may form the gangue; tourmaline and orthoclase may also be present. In what form the gold was extracted from the rocks and transported is perhaps uncertain. The solutions were dilute and the gold reduced to the elemental state by the accompanying sulphides. The presence of carbon or hydrocarbons in the walls of the ore body aids in its enrichment. In the secondary concentration near the surface melanterite has been the precipitant. Gold may occur as a telluride of gold, or

telluride of gold and silver, or free gold in the presence of other tellurides. It occurs with the auriferous silver ores and with the sulphides of other metals in which the gold is present in the elemental state not as a sulphide.

Primary Copper Ores.—Chalcopyrite, chalcocite and bornite appear as primary minerals of hydatogenetic origin. The native copper is either metamorphic or metasomatic in origin. The chalcopyrite is by far the most important contributor to the world's supply of copper, but not all chalcopyrite is primary. The sulphides are derived from either acid or basic intrusives and precipitated by the action H_2S in the heated waters.

Primary Lead and Zinc Ores.—The sulphides of lead and zinc, when filling fissures, appear to be connected with acid intrusives and are most abundant in the Paleozoic rock although they appear in the rocks of all ages. It is from these intrusives that the lead and zinc minerals appear to have been derived.

Primary Silver Ores.—True silver veins are characterized by the presence of original argentiferous minerals as native silver and argentiferous alloys together with the chlorides, iodides, bromides, selenides, tellurides, antimonides, arsenides of silver and other metals.

In Butte, Montana, the silver seems to have been derived from dikes of quartz porphyry cutting granites. At Cobalt, South Lorraine and Gowganda, Ontario, the silver is derived from diabase and gabbro; therefore primary silver deposits may be associated with either acid or basic intrusives.

The sulphides of the other metals also appear as primary ores, when derived from some magma and precipitated by hydrogen sulphide. Two carbonates appear as hydatogenetic minerals, siderite and rhodochrosite; one hydrosilicate garnierite is derived from a peridotite magma in its transition to serpentine and deposited in the numerous fissures by the combined action of lateral secretion and hydatogenesis.

Metasomasis.—According to Le Conte, metasomasis is the process by which change in the mineral composition of a rock is effected. It may be produced in three ways: (1) By the alteration of the original minerals; (2) by the replacement of the original minerals; (3) by the crystallization of the minerals. The three changes may be effected separately or conjointly.

If a limestone should be replaced in part by magnesium carbonate and therefore converted into dolomite, such a dolomitization

would represent a metasomatic replacement. The replacing material is introduced by circulating meteoric waters. The solvent action of the water is increased by the presence of carbon

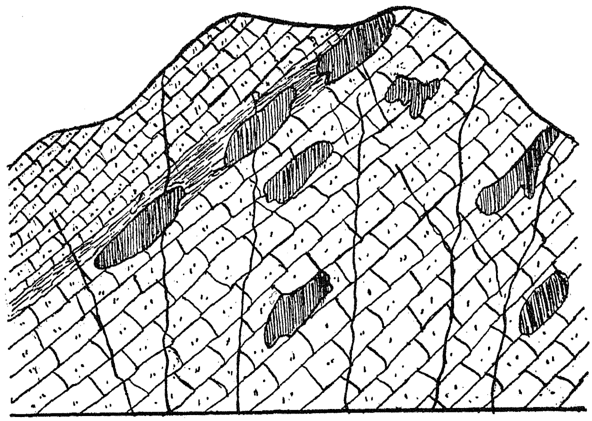


FIG. 24.—Contact deposits in limestone beneath shale.

dioxide under pressure, sulphides and silicates, together with the humic acid of the soil.

Where sedimentaries lie in contact with igneous rocks, iron is leached out of the intrusive and by chemical action deposited

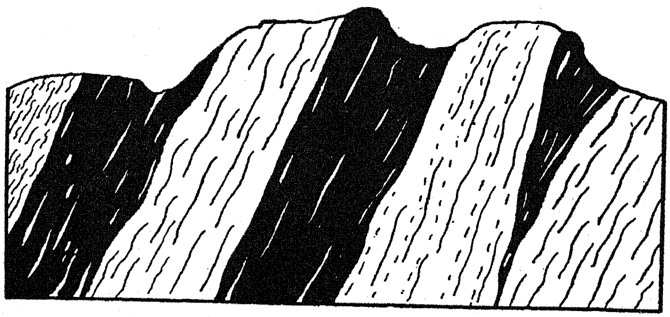


FIG. 25.—Iron ores of Michigan interbedded with sedimentary rocks. (*After Emmons.*)

as an iron ore wherever an equivalent amount of limestone has been dissolved and transported elsewhere by percolating waters (Fig. 24). Metasomatic metalliferous minerals are most common in the sedimentary rocks. They may be deposited soon

after the deposition of the sediments on the floor of the sea, or some later period, either before or after these sedimentaries have become land masses.

Ore deposits thus formed are divided into two classes: (1) Bedded deposits, in which the ore body conforms with the strata

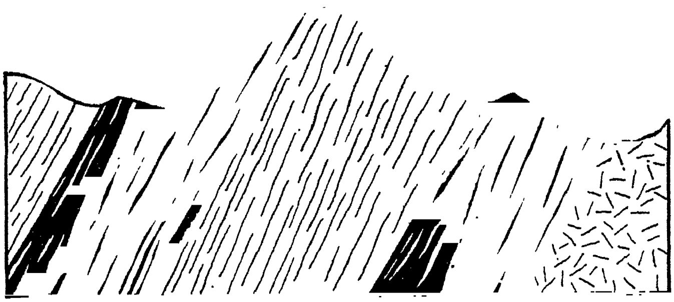


FIG. 26.—Iron ores of Michigan interbedded with igneous and sedimentary rocks. (*After Emmons.*)

in which it lies, as shown in Figs. 25, 26, and 27. (2) Fissure deposits, in which the ore conforms to the fissures and joints of the strata which may cross the sedimentaries at any angle. The former type embraces the most important iron and man-

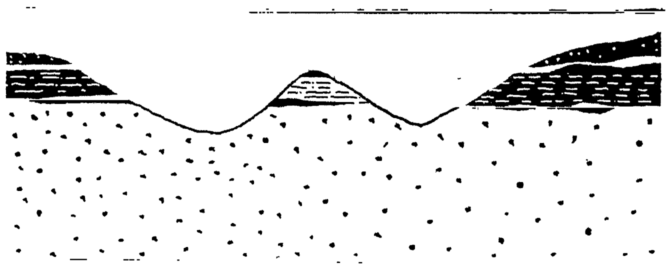


FIG. 27.—Geological section in the manganese region of north Arkansas. The block bands represent beds of manganese that were deposited in layers alternating with the accompanying rocks.

ganese formations, while the latter includes the silver, lead and zinc deposits.

There are three ways of recognizing a metasomatic ore body: (1) The absence of symmetrical banding of its vein material. (2) The absence of breccias cemented by gangue minerals. (3) Lack of definition between the country rock and the ore body.

Metasomatic Iron Ores.—The ores of iron that owe their origin to chemical action through solution and precipitation are the carbonate (siderite), the oxide (hematite) and the hydrous oxide (limonite). (See Fig. 28.)

The source of the iron is generally some neighboring intrusive or pyritiferous sedimentary. The iron is dissolved by percolating waters. The solutions may find their way into strata capable of effecting the chemical change suggested, or find their way into

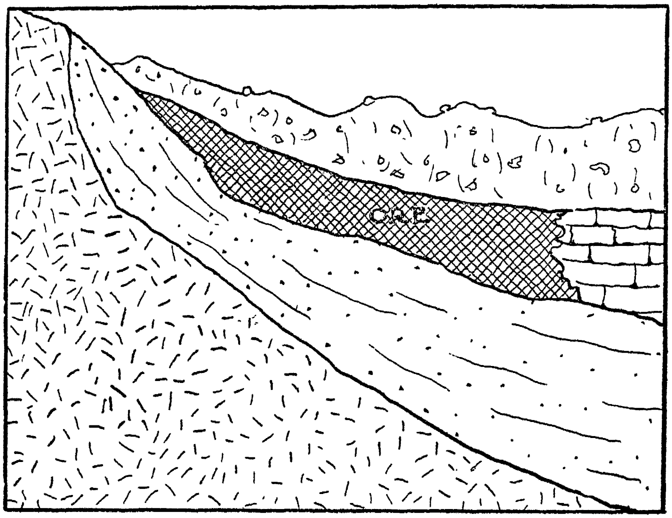


FIG. 28.—Section to illustrate the usual occurrence of iron ore deposits in the Mesabi range. It is below the glacial drift and resting upon quartzite. (*After Winchell.*)

standing waters where the iron can be extracted and deposited by metasomatic action.

Pyrite will oxidize readily to melanterite, $FeSO_4,7H_2O$. Solutions bearing calcium carbonate will bring about the reaction through which the iron would be precipitated as the carbonate and the calcium sulphate will be precipitated as gypsum, $CaSO_4$,-$2H_2O$, or transported elsewhere.

$$FeSO_4 + CaCO_3 = FeCO_3 + CaSO_4.$$

If the percolating waters bear chlorine, the chloride of iron, Fe_2Cl_6, will be formed and calcium carbonate acting upon the

chloride of iron will precipitate the iron as the oxide (hematite), according to the equation:

$$Fe_2Cl_6 + 3CaCO_3 = Fe_2O_3 + 3CaCl_2 + 3CO_2.$$

The iron ore replaces the limestone in the metasomatic deposits molecule by molecule.

Thomas and MacAlister divide the iron ores of metasomatic origin into two classes: (1) Contemporaneous, in which the replacement occurred either during or immediately after the deposition of the original rock. (2) Subsequent, in which the replacement occurred after the deposition and consolidation of the original rock. The former includes the bedded deposits and the latter the irregular patches and veins. The oölitic Clinton iron ore of central New York, Pennsylvania and Alabama is a representative of the contemporaneous deposits. The ore lies above the Medina sandstone in limestones of Silurian age.

The Lake Superior iron ores lie upon the Archean complex and in the Keweenawan terranes. They form the best American representative of subsequent replacement. (See Fig. 29.)

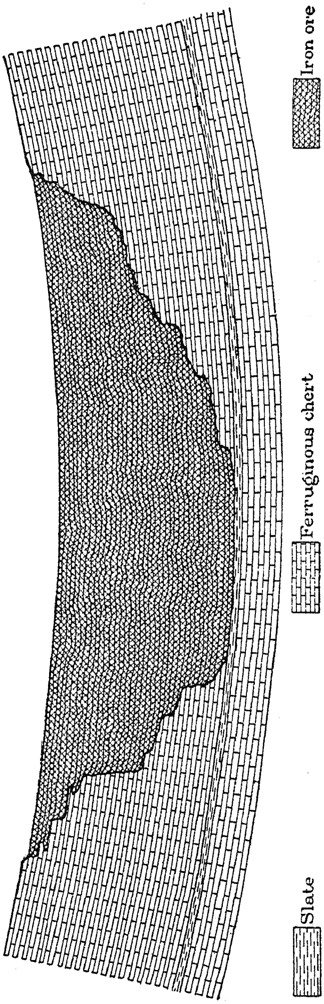


FIG. 29.—Ideal cross section of a Mesabi ore deposit showing relation of ferruginous chert and impervious slate layers. (*After C. K. Leith, U. S. Geological Survey.*)

The source of the iron seems to have been the ancient igneous rock of the Lake Superior region. The iron was precipitated as siderite. The siderite then passed into hematite and insensibly into ferruginous quartz schists, jaspers, magnetite and limonite schists. In the

Mesabi district the iron was originally deposited as the silicate, greenalite.

Metasomatic deposits of Bauxite.—The Georgia-Alabama bauxites are found in Paleozoic limestones above pyritiferous shales. Meteoric waters oxidize the pyrite to ferrous sulphate and sulphuric acid. The free acid attacks the aluminum silicates of the shales producing alum and aluminum sulphates which are carried upward by ascending currents. These solutions, in contact with the overlying limestones, form calcium sulphate and bauxite.

Lead and Zinc Metasomatic Deposits.—Lead and zinc form metasomatic ores in the form of the sulphides, sulphates, carbonates and silicates. The sulphides are of most importance. Such deposits are common in the Carboniferous limestone but may occur in the limestones of any age. In Cumberland, England, the ore takes the form of and replaces the calcareous fossils. The molecular replacement has been so perfect that the ore preserves not only the external form but often the internal structure of the fossils it has replaced.

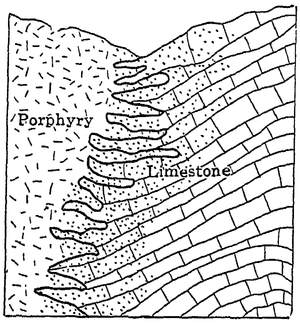


FIG. 30.—Diagrammatic section showing the contact of porphyry and limestone and the zone of ore deposition, Maginnis mine, Judith Mountains, Montana. (*After Weed and Pirsson.*)

The source of the lead and zinc minerals is often in some igneous rocks or sulphide-bearing sediments. These may be beneath the surface or exposed to weathering agencies at the surface. The transporting waters are meteoric and carry the solutions downward where deposition takes place (Fig. 30).

Metasomatic Copper Deposits.—Chalcopyrite, $CuFeS_2$, is the most important copper ore of metasomatic origin. The materials came from some igneous magma during the later stage of its cooling. The aqueous emanation transported the minerals in the form of sulphates. The solutions are either ascending or descending and the chalcopyrite would be precipitated by hydrogen sulphide and alkaline sulphides. If the solution percolated through the limestone, then malachite and azurite would be formed.

Metasomatic Gold Deposits.—According to Thomas and MacAlister, in the Transvaal district, siliceous gold-bearing solutions

acting upon pyrite below the permanent water level, in the presence of a deficiency of oxygen caused a partial oxidation of the pyrite and a consequent metasomatic deposition of the gold.

Precipitation.—Precipitation is the process by which certain constituents of a solution are rendered insoluble in that solution. This is effected in the laboratory by the lowering of the temperature, by the evaporation of the solvent, or by double decomposition. In nature the fall of temperature occurs with rising thermal waters, but ores thus precipitated would be rare. The evaporation of the solvent is common and metallic ores may thus be thrown out of solution. The most common cause of precipitation is the mingling of different solutions in the trunk channels.

Siderite and rhodochrosite are held in solution in waters charged with carbon dioxide. If the carbon dioxide be extracted by relief of pressure, or by any other cause, these metals are reprecipitated as carbonates and remain as such in the absence of oxidizing agents. The sulphides of many metals are precipitated from their sulphate solution by the action of organic matter, or by the action of hydrogen sulphide upon their acid solution, while others are precipitated as sulphides from their alkaline solutions. Precipitated bedded ores may occur as sheets between sedimentaries, or as crystals, grains, or nodules in the sedimentaries.

These deposits may be recognized: (1) By parallelism with the enclosing sedimentaries; (2) by their occurrence in different horizons; (3) their margins are clearly defined; and (4) they do not shade into the barren country rock.

Iron and Manganese as Oxides.—These occur as bog-ores. Iron and manganese are thrown out of solution as a mixture of hydrated oxides by the action of algæ and bacteria. Siderite may be brought into solution by percolating waters and when oxidized thrown out of solution as ferric hydroxide, according to the equation:

$$4FeCO_3+O_2+3H_2O=Fe_2(OH)_6+Fe_2O_3+4CO_2$$

The primary source of the iron and manganese is the ferromagnesian silicates of the igneous rocks. The pyrite of the sedimentaries also is oxidized or decomposed by humic acid and rendered available for precipitation. These minerals of iron and manganese had their primary source in the igneous rocks which furnished the detritus from which the sedimentaries were formed.

In carbonaceous shales the iron and manganese minerals are precipitated as carbonates by the loss of carbon dioxide from their solutions and the reducing action of organic matter. The ore deposits thus precipitated occur either as continuous sheets or as bands of concretionary minerals. (See Fig. 31.)

The sulphides of these metals occur as precipitates in bedded deposits either through the action of H_2S upon their solutions or by the reduction of their soluble sulphates. In the Harz Mountains, the sulphide of copper occurs in bedded deposits that appear to have been reduced from sulphate solutions by the action of decomposing organic matter.

Gold is precipitated in siliceous sinter in Queensland, Australia,

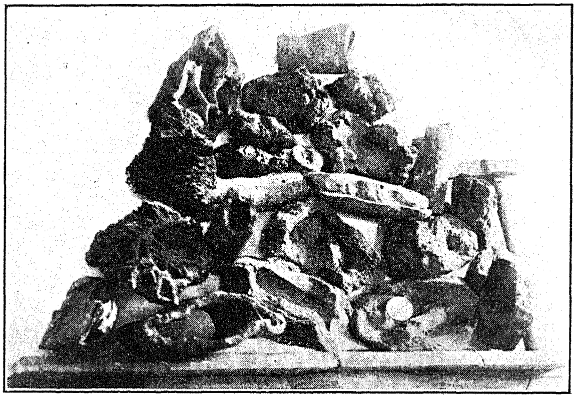


FIG. 31.—Limonite concretions in the Kittany Valley, Pennsylvania. (*Photograph by T. C. Hopkins.*)

where the sinter has been deposited from highly alkaline siliceous waters. This ore has yielded over $350 per ton in gold.

A few precipitates as silicates are well known. Illustrations may be cited in the greenalite of the Mesabi iron district, Minnesota, and the glauconite or green sand marl, of New Jersey.

Metamorphism.—Metamorphism is the process by which a complete or nearly complete chemical change has been effected in an ore body. These changes may take place either in the upper part of lodes and bedded masses exposed to percolating meteoric waters or at considerable depths below the surface by thermal and dynamic agencies. The first implies the downward transference of minerals in solution for the subsequent enrichment of metalliferous deposits; the second, the reconstruction of an ore

body or rock mass by the influence of high temperature or by shearing stresses of sufficient intensity to generate considerable heat. The heat necessary for metamorphism may arise from the intrusion of a fluid magma or from the internal heat of the earth. Dr. F. W. Clarke, in his "Data of Geochemistry" cites the following changes as the most important:

(1) *Molecular Rearrangement.*—By this process a pyroxene is converted into an amphibole.

(2) *By Hydration.*—The conversion of a peridotite or a pyroxenite into a serpentine or steatite would represent the change.

(3) *By Dehydration.*—Limonite, $2Fe_2O_3,Fe_2(OH)_6$, is converted into hematite, Fe_2O_3, and bauxite, $Al_2O_3,2H_2O$, into corundum, Al_2O_3.

(4) *Oxidation and Reduction.*—Through oxidation ferrous compounds become ferric. Through reduction hematite, Fe_2O_3, becomes magnetite, Fe_3O_4.

(5) *Changes other than hydration* produced by percolating solutions. The transference of some cement into a sandstone and its conversion into a quartzite would be an example.

(6) *Metamorphism by the action of gases and vapors*, the so-called "mineralizing agents." The process generates new minerals and introduces new solutions.

(7) *Metamorphism by Igneous Intrusion.*—By this process new minerals are developed in the metamorphic aureole.

The ores associated with metamorphic rocks may be divided: (1) Into those which occur as layers or lenticles in the crystalline schists, and (2) those which occur as metamorphosed metasomatic deposits of irregular shape.

In the crystalline rocks, hematite and magnetite are often of commercial significance. The hematite is produced by the dehydration of limonite and the magnetite by the reduction of hematite or by the decomposition of siderite through a loss of carbon dioxide.

As sulphides, chalcopyrite, galenite, sphalerite and pyrite are common in Scandinavia. While not of so great importance in themselves alone, they have been the source of the material for the enrichment of the lodes, traversing the district. The magnetite ore bodies of the Adirondacks, New York, represent a metamorphosed deposit in the older schists and gneisses. (See Figs. 32 and 33.)

Another illustration may be cited in the famous hematites and

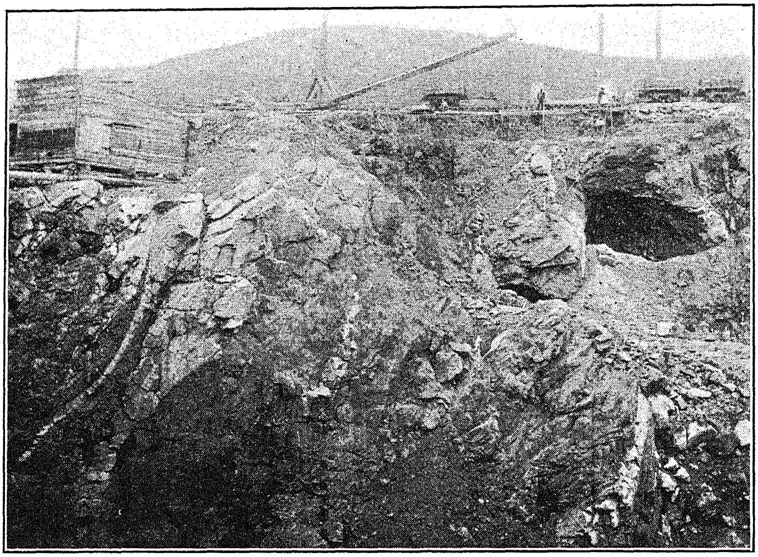


FIG. 32.—Iron mine, Lyon Mountain, New York. (*Photograph by T. C. Hopkins.*)

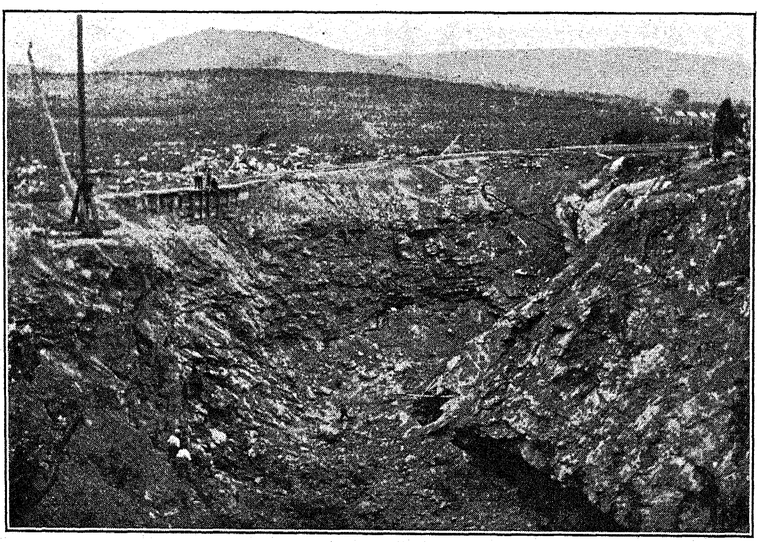


FIG. 33.—Iron mine, Lyon Mountain, New York. (*Photograph by T. C. Hopkins.*)

magnetites of Constantine, North Africa, noted for their remarkable freedom from sulphur and phosphorus.

The zinc-manganese mineral franklinite at Franklin Furnace, N. J., occurs in a metamorphosed limestone with zincite, willemite and rhodochrosite.

Corundum, ruby, sapphire and emery occur in the metamorphosed schists and limestones. The famous emery deposits on

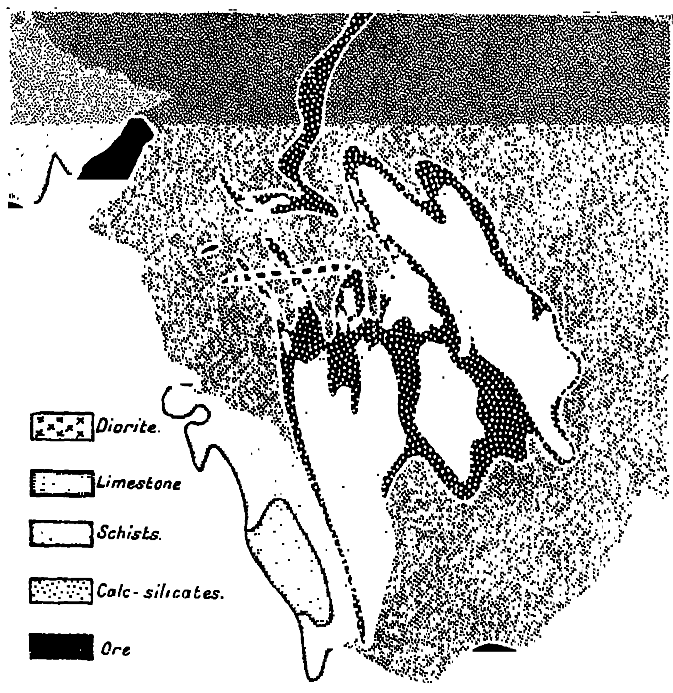


Fig. 34.—Map of the district of Persberg, showing the association of the ore with metamorphosed calcareous rocks. (*After Sjorgren.*)

the Island of Naxos in the Grecian Archipelago occur in a metamorphosed limestone. Metamorphic ore deposits may be recognized by their associated minerals and their mode of occurrence. Metamorphic contact deposits are not distributed over large areas but rather confined within the metamorphic *aureole* in which the change has been effected through the influence of some intrusive.

The changes produced in an ore body are along the lines of de-

hydration and recrystallization. The intrusives may also bring in new minerals by means of the heated solutions given off by the magma during the last stages of its consolidation which bridges the gap between pneumatolysis and metasomasis. (See Fig. 34.)

Metamorphic masses of hematite, magnetite and pyrolusite occur in association with the intruded porphyry at Santiago, in Cuba. The copper deposits at Bisbee, Arizona, must in part be catalogued as metasomatic, yet these copper ores occur within as well as without the metamorphic aureole and associated with a porphyry magma.

At Deep Creek, Utah, gold occurs as a metamorphic contact deposit in masses of granite and porphyry intruding the limestone. At the contact of the intrusive with the limestone, garnets and tremolite occur in abundance. The gold occurs both in a finely divided state in the recrystallized limestone and in threads in masses of tremolite.

Secondary Changes.—Secondary changes in ore bodies are effected; (1) By oxygenated meteoric waters, and (2) by waters derived from depth. The process often involves solution and the transference downward of the more soluble minerals for enrichment of the lodes at the lower levels. The extent to which the alteration will extend depends upon: (1) The relation of the rock to drainage; (2) the level of the ground water, and (3) the humidity of the climate.

By glacial erosion in northern areas and continental denudation everywhere, the changes are carried progressively to lower levels. In the secondary changes by ascending solutions the older minerals are replaced by the newer, as at Comstock Lode, Nevada, where calcite is replaced by quartz. The change is generally effected by solutions of a later period of mineralization.

The possibility of these deep-seated changes was pointed out by J. H. L. Vogt, who showed that by either hot air or superheated steam, argentite may be converted into native silver and sulphur dioxide according to the equations:

$$Ag_2S + O_2 = 2Ag + SO_2$$
$$Ag_2S + H_2O = 2Ag + H_2S + O.$$

or on copper ores:

$$2Cu_2S + 6O = 2Cu_2O + 2SO_2.$$
$$Cu_2S + 2Cu_2O = 6Cu + 2SO_2$$
$$Ag_3AsS_3 + 3H_2O = 3Ag + As + 3H_2S + 3O.$$

Weathering changes effected in the upper part of lodes are in part oxidation and in part reduction. The upper part comprises a zone of oxidized minerals. Beneath this there is a zone of enriched ores, often the richest portion of the entire lode, beneath which there is a zone of permanent value.

In the oxidation of chalcopyrite, ferrous sulphate is formed, which is readily oxidized to ferric sulphate. The ferric sulphate reacts upon the chalcopyrite, reducing the mineral to chalcocite, and by further influence of the ferric sulphate the chalcocite is converted into the sulphate of copper, according to the equation:

$$Cu_2S+5Fe_2(SO_4)_3+4H_2O=2CuSO_4+10FeSO_4+4H_2SO_4.$$

The copper sulphate in solution is transferred downwards to be reduced by the pyrite or other sulphides according to the equations

$$7CuSO_4+4FeS_2+4H_2O=7CuS+4FeSO_4+4H_2SO_4$$
$$11CuSO_4+5CuFeS_2+8H_2O=8Cu_2S+5FeSO_4+8H_2SO_4.$$

The copper sulphate in the presence of either pyrite or troilite may be converted into chalcopyrite, as, for example, on Vancouver Island. The carbonates of copper are less soluble than the sulphate. If calcium carbonate in solution is transported downward in the copper lode, malachite or azurite and calcium sulphate would be formed with the liberation of carbon dioxide. The chalcanthite in solution may be reduced to tenorite, $2CuSO_4+2CaCO_3=2CuO+2CaSO_4+2CO_2$, which in contact with ferrous sulphate solutions would be reduced to cuprite, Cu_2O, and ultimately to native copper.

Cerussite and anglesite, the carbonate and sulphate of lead, are similarly formed direct from galenite, while native silver is often produced by the reducing action of decomposing pyrite upon the sulphate of silver.

Detrital Deposits.—Detrital deposits are those resulting from the disintegration of rock masses through atmospheric agencies. The more resistant the parent rock the shallower the deposits become. If the gradient of the stream in the valley is small, the deposit will concentrate near the source of the ore. The higher the gradient and the greater the velocity of the stream, the farther down the valley the metalliferous minerals will be carried (see Fig. 35). The composition of the detrital deposit will depend upon the nature of the overlying country rock and the assorting power of the associated waters, as shown in Fig. 36.

Placers represent the concentration of the heavier economic minerals in the order of their decreasing density. In shallow

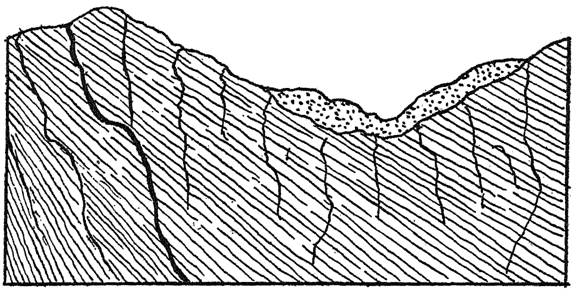


FIG. 35.—Theoretical section showing the origin of auriferous gravels. The dark lines represent gold-bearing veins of which the coarser and heavier materials accumulate in the valleys.

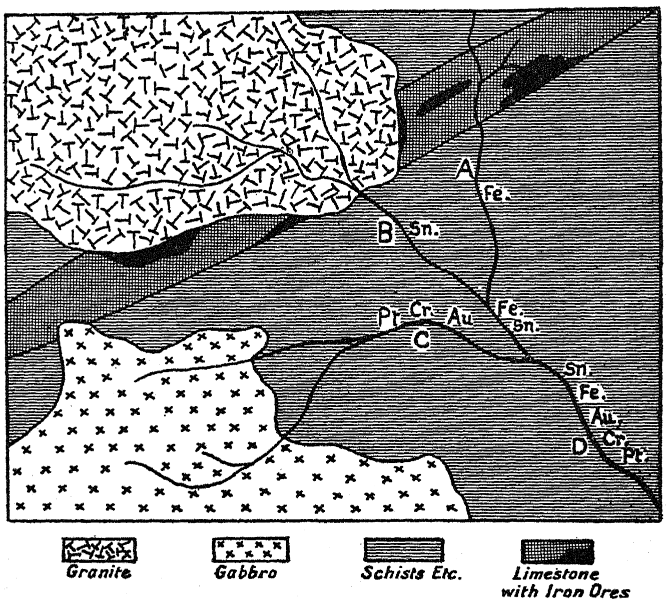


FIG. 36.—Map to illustrate the influence of ore-bearing rocks on the alluvia of streams and rivers. (*After Thomas and MacAlister's Geology of Ore Deposits.*)

placers the metalliferous mineral is confined to one level. In the deep leads there are two or more levels at which the values may be

obtained. Deep leads therefore mark a cessation in the deposition of sediments. It may be that the stream was turned into some other channel by geological changes and subsequently returned again to the same valley. (See Figs. 37 and 38.)

Laterite is the name applied to deposits arising through the

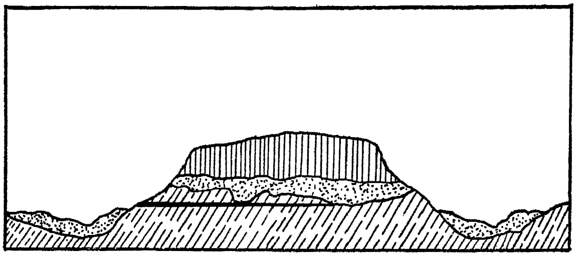


FIG. 37.—Section through Tuolumue County, California, showing old river auriferous gravels covered by a bed of lava, and the method of tunneling to reach them, at the sides are shown river gravels of a later age.

solution and oxidation of certain minerals. The metalliferous minerals in such cases lie near the base of the hills, composed largely of basic intrusives which have been the source of the ore. Such deposits are represented in the Appalachian belt, India, Madagascar and elsewhere.

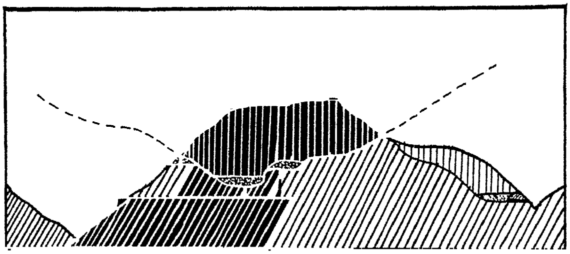


FIG. 38.—Section through the Red Point and Damm Channels from El Dorado Canyon (right) to Humbug Canyon, California, showing the auriferous gravels covered by lava, and the method of reaching them by tunneling. The dotted lines at the sides suggest the ancient outlines of the hills.

Gold.—Placer deposits are one of the most important sources of this precious metal. In the Black Hills of S. Dakota, and in Alaska the gold has been concentrated by wave action. It is derived from pre-Cambrian metamorphics traversed by quartz veins.

In the detrital deposits of the Transvaal it is considered by some authorities that by the absence of nuggets the gold must have been deposited by subsequent infiltration into the conglomerate with which it is associated. The arguments in favor of its detrital origin are: (1) Gold is restricted to the conglomerate; (2) the coarser the conglomerate the richer it is in gold content; (3) it was present in the conglomerate before much erosion took place; (4) it is independent of dikes and faults; and (5) it is independent of those sulphides which serve as precipitants for gold.

In Australia the detrital gold deposits have furnished one nugget weighing 233 lb., but as a mass of gold weighing 140 lb. has been found in quartz reefs, the larger nugget may be of detrital origin. However, through chemical affinity, small particles of gold are often welded together.

Platinum.—Platinum is derived from two types of rocks, the ultra-basic and the basic intrusives, while detrital gold is often derived from both the acid and basic igneous rocks. The rare metals of the platinum group as osmium and iridium are also found in the platinum placers. The Ural placers are the richest in the world in platinum, but placers containing both platinum and gold are found in California.

Iron.—Iron occurs abundantly as beach placers in the United States and New Zealand, but it is seldom present in considerable quantity in other forms than oxides. The black sands of many river valleys are auriferous but they consist essentially of magnetite derived from the basic intrusives associated with its genesis.

Tin.—The most important tin deposits of the world are detrital. The oxide of tin, cassiterite (SnO_2), stoutly resists disintegration. During the erosion of the granites, pegmatites and contact metamorphics the tin finds its way toward the bottom of the detritus. It has been found in beach placers in England and in torrential placers in Bolivia.

The tin deposits of the Federated Malay States are the most important in the world. The acid intrusives forming the high lands have suffered decomposition and erosion and cassiterite has become the chief detrital placer mineral.

On the Islands of the Banka and Billiton the tin deposits occur in two forms; (1), "shoad" deposits in which the ore is found near the lodes from which it was derived; and (2), the deep lead placers which may extend over considerable area and varying depths.

Assorted Minerals.—These are often of no economic significance

in themselves alone but their constant occurrence in a placer implies the presence of a precious or useful metal. Cinnabar and wolframite indicate that the placer may carry gold; topaz and tourmaline signify the possible existence of tin; while chromite is an invariable associate of platinum.

CHAPTER III

PRECIOUS METALS

GOLD, SILVER AND PLATINUM

Properties of Gold.—Gold, symbol Au, is a soft yellow metal unaffected by either moist or dry air. It is insoluble in all single acids save selenic. It surpasses all other metals in its malleability and ductility. Its specific gravity is 19.3; melting-point, 1065° C. and atomic weight, 197.2.

Ores Containing Gold.—*Native gold:* Pure Au is sometimes found but most of the native gold contains a small amount of silver platinum, etc. *Petzite* $(Ag,Au)_2,Te$: In ratio of 3 : 1 the gold content would be 25.5 per cent. *Hessite* (Ag_2Te): Gold is often present replacing a part of the silver. *Sylvanite* $(Au,Ag)Te_2$: If the ratio is 1:1 it would give 24.5 per cent. gold. *Calaverite* $(Au,Ag)Te_2$: with ratio 7:1 it would contain 39.5 per cent. gold. *Krennerite* (Ag_2Te,Au_2Te_3): The per cent. of gold is 35.5. *Nagyagite* $(Au_2,Pb_{14},Sb_3,Te_7,S_{17})$. Some samples have given upon analysis 12.75 per cent. of gold.

Occurrence.—Gold occurs native encased within quartz. Sometimes in a finely divided state, sometimes in particles of considerable size, as nuggets, grains, scales, plates, threads and wires in quartz rock. It is often encased in pyrite, chalcopyrite, arsenopyrite, magnetite and hematite. It occurs also in a finely divided state in schistose rocks, often in too small quantity to pay for profitable extraction. It has been observed in the process of deposition at Steamboat Springs, Nevada. It is present in sea water, especially along the coast of Norway. It has been detected in many saline minerals, as sylvite, kainite, halite, and carnallite. It has also been found in the ashes of sea weeds. An attempt was made several years ago to reclaim the gold from the sea waters of the northeastern coast of the United States, and although the metal appeared in considerable quantity, the effort proved futile.

The percentage of gold in sea water varies. It is present in greatest abundance where meteoric waters, flowing freely through

gold-bearing belts, reach the sea. In the Appalachian belt, there is gold in the schistose rocks. Therefore along the Atlantic coast it is manifestly present in the sea water. Australia has many gold deposits, and meteoric waters flowing in rivers to the sea naturally carry some gold to the sea.

The compounds of gold occurring as minerals of economic importance are few. The combination is generally with telluruim as petzite, $(Ag,Au)_2Te$, in which the silver and the gold vary somewhat but represent the unit structure in the mineral.

Hessite shows no gold in the formula, Ag_2Te, but gold may replace the silver to a considerable extent. There is theoretically at least every gradation between the true telluride of gold on the one hand and the telluride of silver on the other. In the telluride of gold, silver is generally present and in the telluride of silver, gold is usually found. Calaverite, sylvanite, krennerite and nagyagite are also important sources of gold. The last named mineral is best catalogued as a sulpho-telluride of lead and gold. Kalgoorlite and coolgardite are examples of the tellurides of gold, silver and mercury. Gold occurs also as an amalgam with mercury, and as an alloy with copper, bismuth, platinum and rhodium.

A word may be said here with reference to the occurrence of gold as a sulphide. The proofs of its occurrence as such are inadequate. The sulphide of gold is exceedingly unstable whenever the precipitation occurs in chemical laboratories or the laboratory of nature by the action of hydrogen sulphide upon the neutral or slightly acid solution of the metal. Its instability favors its immediate reduction to the elemental state, provided any reducing agent is present.

The sulphide of iron which is an exceedingly common associate with gold serves as such a reducing agent. Therefore whenever gold is found encased in pyrite, it is always present as free gold and not as a sulphide. Therefore the existence of auric sulphide, Au_2S_3, in nature may be questioned.

Gold is found widely diffused in nature although one of the scarcer metals. It appears both in the igneous rocks and the sedimentaries, and manifests itself in the metamorphic rocks both of igneous and sedimentary origin. When occurring in igneous rocks the ore is of primary origin; when in fissure veins it is of pneumatolytic origin; when in sedimentary rocks it is of secondary origin. Its favorite gangue mineral is quartz often associated with fluorite and pyrite. Its occurrence in the granites of Mexico

and their metamorphic derivatives proves that gold is more likely to be found in the acidic than in the basic rocks. It has, however, been found in basic rocks, and this occurrence is not rare.

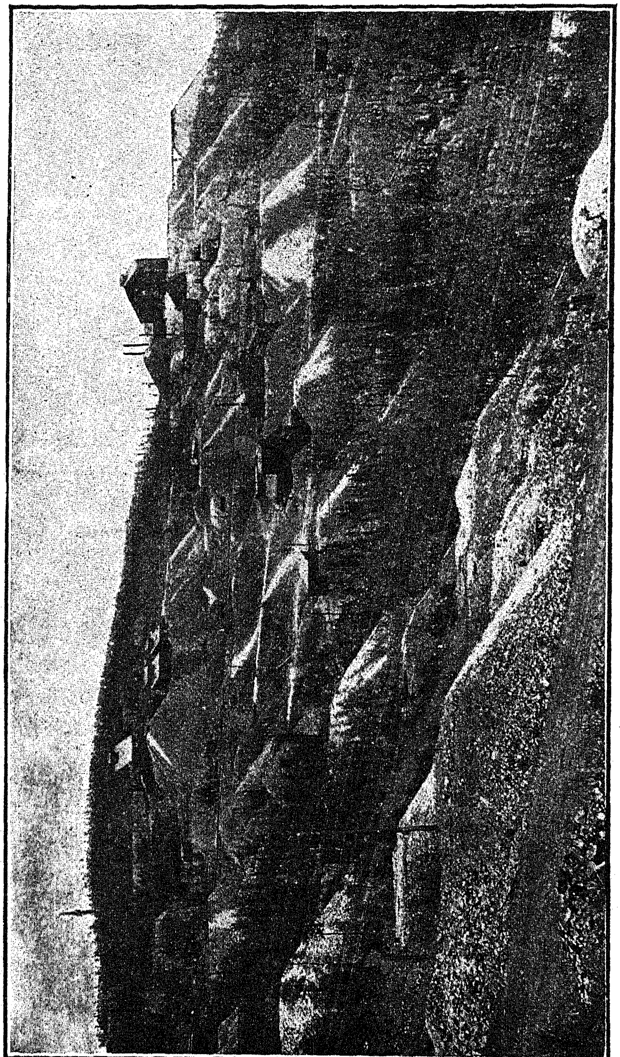


FIG. 39.—North Slope of Gold Hill, Cripple Creek district, Colorado, Anchoria-Leland mine on the right. Half Moon mine on the left. *(After W. Lindgren and F. L. Ransome, U. S. Geological Survey.)*

The auriferous quartz veins are doubtless free from silver in most cases. In some cases, it has been suggested by J. E. Spurr of the United States Geological Survey, that they represent

magmatic segregation. The same idea has been advanced by C. R. Van Hise of the University of Wisconsin. Again it has been shown by Thomas and MacAlister in their "Geology of Ore

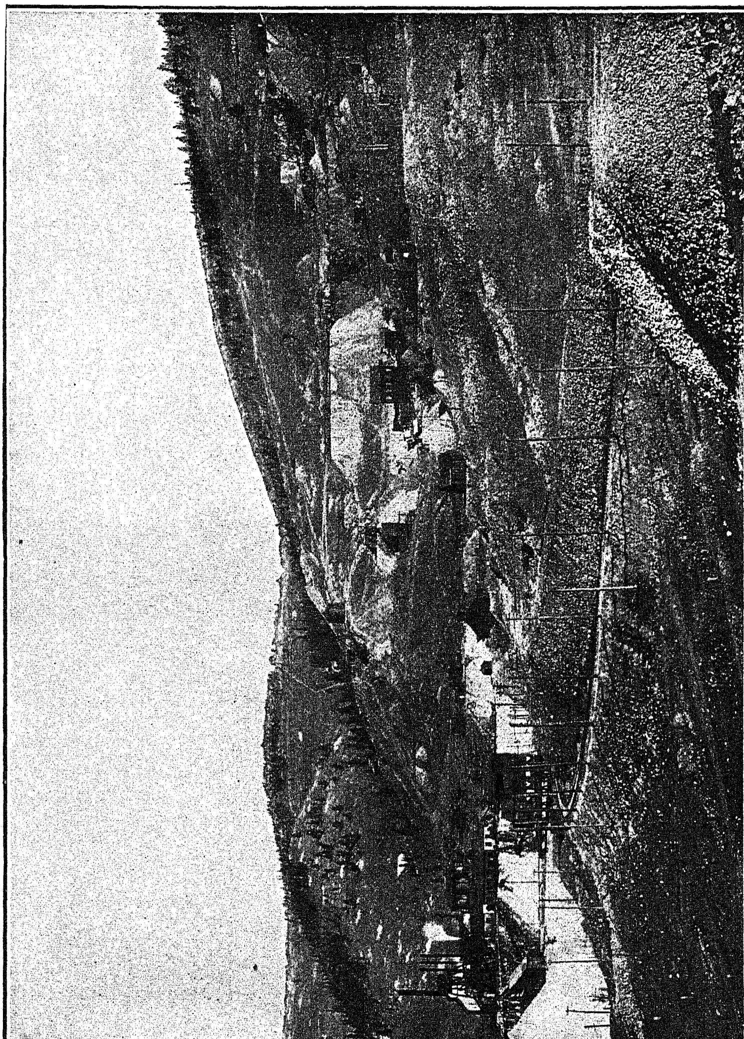


Fig. 40.—West-slope of Raven Hill, Cripple Creek district, Colorado, showing Doctor-Jackpot and Morning Glory group of mines. (*After W. Lingdren and F. L. Ransome, U. S. Geological Survey.*)

Deposits" that the composition of gold is variable. If any metallurgical plant produces gold as pure as 0.999 fine it is only by the most careful method of treating the ore.

The elements associated with gold are silver, copper, mercury, platinum, bismuth, iron, rhodium and tellurium. Gold occurs also as an incrustation upon other minerals, and deposits on twigs in the Hot Springs of New Zealand have been found. It has also been detected as a cement joining fragments of quartz. These occurrences all lead to the conclusion that secondary gold is deposited from solution, and that primary gold is of magmatic origin (Figs. 39 and 40).

Character of Ore Bodies.—A very common occurrence of gold is in true fissure veins, even and perhaps more abundant, in seams

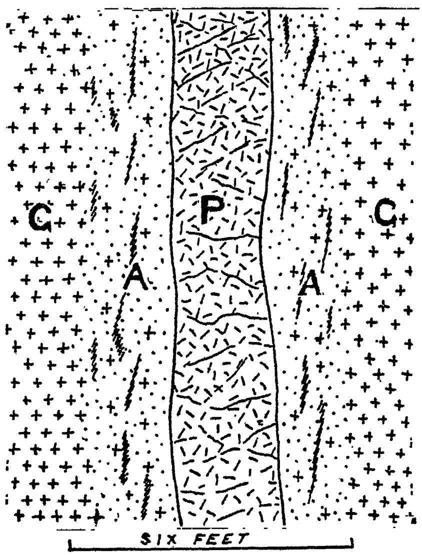


FIG. 41.—Gold Vein, Cripple Creek, Colorado. *G*, Granite; *P*, phonolite *A*, altered, impregnated granite, with strings of fluorite and gold ore. (*After T. A. Rickard, U. S. Geological Survey.*)

or layers in close proximity to the hanging wall, occasionally migrating across the fissure vein and in close proximity to the footwall. Fissure veins often fluctuate in value, so that the ore richest in gold occurs in pockets, or "bonanzas" as the miner says. In some mining belts one may by systematic drifting along the direction of the main fissure vein encounter a "bonanza." Where the normal concentration or value through the vein would be from \$6 to \$10 per ton, a pocket might be represented by a richness of \$50,000 or even \$100,000 per ton. It often occurs that

drifting along the line of the vein must be carried for thousands of feet in ore that does not pay for the extraction of the metal before such a pocket is encountered. Again, the line carrying the gold may be simply a thin seam or film, so that all the ore workable with profit may be deposited from solution on a film so thin as to be almost invisible to the naked eye. Sometimes the material of the entire vein is rich enough to pay for the profitable extraction of the metal. This is especially true in some gold mines of British Columbia and Alaska. The ores are more likely to be spotted than otherwise, that is, gold occurs in small pockets.

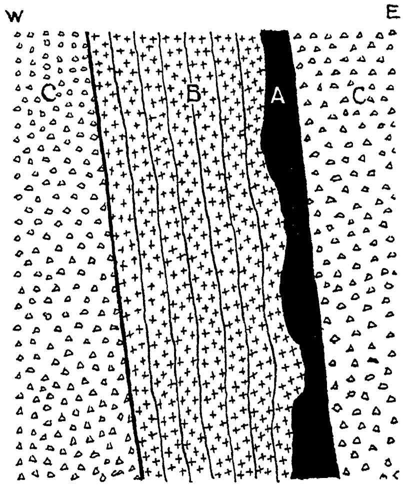


FIG. 42.—Section in the Elkton mine, Cripple Creek district, Colorado, showing the relation of the vein *A* to the dike *B* and to the country rock *C*. (*After Penrose.*)

rather than with a uniform distribution throughout the entire vein. The vast majority of gold deposits within the United States occur in true fissure veins. (See Fig. 41.)

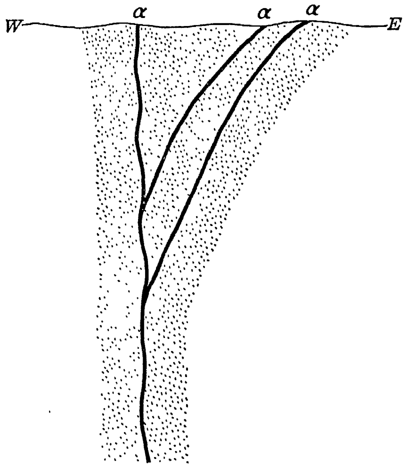
The second type is known as the propylitic in which through the metasomatic alterations of the wall rock there is developed secondary minerals such as chlorite and epidote, the former resulting from the metamorphism of various micas, the latter from the alterations of feldspars. These propylitic types are in close proximity to veins of sericite and kaolin. The first type occurring with quartz gangue in true fissure veins is seldom highly argentiferous, the second type in which kaolinization has taken place is

often rich in silver content or highly argentiferous. The character of the rock which the vein traverses is often variable, for the gold-bearing veins appear in either igneous or sedimentary rocks, sometimes at the contact zone between igneous and sedimentary rocks, little influenced by the character of the rock which the vein traverses save in the case of replacement (Fig. 42). Again, true fissure veins, in the more recent lava flows, often appear intimately associated with tellurium, and these often give rise to pockets of great richness. In the telluride group the ores occur either as definite tellurides of gold with silver, lead and antimony, or as native gold accompanied with various tellurides. The gangue minerals are quartz and fluorite; calcite may be sparingly present. In Boulder County, Colorado, roscoelite, a vanadium mica, is associated with the tellurides.

Classification.—Gold deposits are often classified according to their association. The first of these may be catalogued as gravel deposits. It includes all classes, whether as river or beach gravels or covered with volcanic material. The gold appears as a result of the disintegration of superincumbent strata where the gold by its insolubility and the higher specific gravity has been transported to lower altitudes in the adjacent valleys. Pay gold is not transported far from the site of its parent rock. The lower portions of the gravel bed are generally richer in gold than the upper layers because of the higher specific gravity of the metal. Where the rocks are fractured as by joint planes, fissures, and the action of the frost, these places of breakage are often found well studded with gold so that 2 or 3 ft. of the decomposed and altered bed rock is removed for the extraction of the gold it contains. It seems that some gold-bearing gravels decrease in richness toward the surface, and then there will appear a rich layer of greater or smaller width than the zone of extreme richness at the bottom of the placer. This implies that there was a cessation in the delivery of auriferous gravel, and then a return of the original stream to the valley, carrying a second contribution of auriferous gravel over the same course as the former. Ordinarily there is only one zone in the gravel and that directly at the base, but where others occur it must imply that there was some disturbance or cessation in the delivery.

The second class of gold ores (Fig. 43) may be catalogued as quartzose. This implies that the gangue mineral is acid, that is, quartz, and that fluorite may abound, or even the other gangue

minerals of the alkaline earth group. Not infrequently there appears within the quartz varying amounts of pyrite, and even limited quantities of copper and lead. These are free milling



F G. 43.—Vertical section showing the forking of the Pike's Peak vein, Cripple Creek district, Colorado. (*After Penrose.*)

ores. By a free milling ore is meant one that does not require roasting before amalgamation will take place. Dry ore is the term often used (Fig. 44).

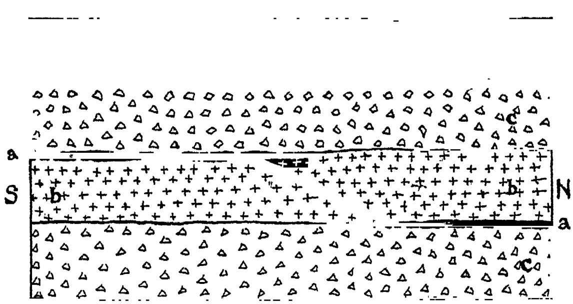


FIG. 44.—Horizontal section in the Elkton mine, Cripple Creek district, Colorado, showing the relation of the vein *a* to the dike *b* and to the country rock *c*. (*After Penrose.*)

The third class of gold ores is auriferous copper ores. These are widely distributed throughout the United States and much of the chalcopyrite is gold bearing. Yet in many cases the yellow

metal is not present in sufficient quantity to warrant its extraction. These auriferous copper ores are especially abundant in Colorado, Utah, Montana and British Columbia. Also at Gold Hill, North Carolina and in Newfoundland.

The fourth class of gold ore is auriferous lead ores. The percentage of lead is large and the gold content often small. They are refactory ores like the copper ores. By refactory ore is meant one that requires roasting before amalgamation will take place. The heavy sulphides as copper, lead and antimony require this method of treatment, that is the condition of the gold in the mineral will not allow of its immediate union with mercury upon the amalgamation plates.

The fifth class of gold ores comprises the gold-telluride group. The gold telluride ores occur with silver, or with silver, lead and antimony, or as native gold accompanied by other tellurides. These ores are often sent direct to the smelters for treatment.

Geographical Distribution of Gold.—Gold is widely distributed in nature. It is present in almost all rocks, but only in a few localities in sufficient quantity for profitable extraction. If a line is drawn from Lake Winnipeg on the north southwesterly to the eastern base of the Rocky Mountains and from thence southerly to the Rio Grande River, nine-tenths of all the gold of the United States lies west of that line.

The American belt then may be divided into five areas: (1) The Appalachian region, (2) the Black Hills region; (3) the Cordilleran region; (4) the Pacific Coast belt, and (5) the Alaskan belt.

Appalachian Region.—The Appalachian field stretches in a northeasterly direction from Alabama on the south, to Newfoundland on the north. It carries varying quantitites of gold. The richest portion is in the southern part of the belt. Hundreds of samples from this belt have shown traces of gold in almost all cases. In the northern portion of the belt, at Newport, Vermont, samples from Cambrian sericite schists have contained over $20 in gold per ton of ore. Near Lisbon, N. H., is found the best representative of gold deposits in the northern half of the belt. Samples containing more than $500 in gold per ton have been assayed. A small mill is treating some of the ore but the output is small. The ore occurs in a fissure vein traversing the crystalline rocks. The gangue is quartz, and in the upper portion of the lode the associated pyrite has suffered much oxidation.

The Southern Appalachian Field: The gold fields of the South-

ern Appalachians are situated in an area of crystalline rocks whose general strike is northeast and southwest. The auriferous rocks consist of granites, gneisses, schists, slates and shales. The auriferous quartz veins coincide imperfectly with the dip and strike of the strata.

In Alabama there are 3500 square miles of auriferous crystalline rocks in Chambers, Chilton, Clay, Cleburne, Coosa, Elmore, Randolph, Talladega and Tallapoosa Counties. The gold is encased in glassy quartz associated mainly with pyrite.

In Georgia the auriferous belt extends in a northeasterly direction across the entire state. The associated rocks are sheared acid and basic intrusives. Certain bands of gneisses and amphibolites have been produced in the shearing, and their fissures are filled with auriferous quartz associated with pyrite.

The southern Appalachian gold field reaches its maximum importance in the Carolinas. From the northern part of South Carolina it extends across the entire state of North Carolina in a northeasterly direction to Virginia. It has a maximum width of 50 miles, and is flanked upon the west by an extensive granitic area and upon the cast by Jura-Trias terranes. The gold occurs in fissure veins with a quartz gangue, and as pyritic impregnation deposits with irregular and lenticular quartz intercalations in the schists and slates.

The age of these ores is in all probability Algonkian for their deposition took place subsequent to the development of the schistosity of the Algonkian slates. The gold in the Jura-Trias conglomerate must have been pre-Jura-Triassic.

The South Mountain belt is situated in the western part of North Carolina. The principal mining region is 25 miles long and about 12 miles wide. The terranes are chiefly biotite schists and hornblende gneisses. The schists are regarded as metamorphosed granites and diorites. They are often garnetiferous and of special interest as they bear the rare minerals ziroon, monazite and xenotime. The strike of these terranes is northeasterly and their dip is about 25°. The gneisses contain isolated masses of pyroxenite and amphibolites often metamorphosed into talc and serpentine.

The auriferous quartz veins are noted for their remarkable regularity. Their general strike is N. 60° to N. 70° E. and dip at a steep angle to the northwest. The veins are exceedingly narrow averaging less than 6 in. The gangue is usually a milky

quartz and somewhat cellular from the oxidation of pyrite. The veins were filled from ascending gold-bearing solutions. The pyrite would serve as a reducing agent for the gold thus held in solution.

The principal mining ground is in placers which, according to E. T. Hancock, may be divided into three classes. (1) The gravel of the stream and bottom lands, deposited by fluviatile action. (2) The gulch and hill-side deposits or accumulations due to disintegration and motion induced by frost action and gravity. (3) The upper decomposed layers of the country rocks in place.

The Virginia belt extends from North Carolina in a northeasterly direction to Montgomery County, Maryland, and is from 10 to 20 miles in width. The terranes consist largely of mica schists and gneisses, often garnetiferous, talcose and chloritic. The auriferous veins conform largely to dip and strike of the schists. They are very irregular, lenticular and narrow, seldom exceeding a few feet in width. The chief gangue is quartz but the wall rocks are often impregnated with auriferous pyrite. The Fisher lode in Louisa County is the most persistent. This lode has been opened for a distance of more than 5 miles, but the maximum depth to which the lode has been worked is approximately 250 ft.

Black Hills District.—The Black Hills are situated in Lawrence County in the western part of South Dakota. The auriferous ores are in the northern Black Hills. The gold of South Dakota was first discovered in the placers which occupy depressions in the pre-Cambrian schists. The region in one of peculiar interest for it represents some of the earliest known and worked placers of the United States. After the placers became somewhat exhausted at the surface, the workings were carried downward into the conglomerate that marks the base of the Cambrian series of rocks.

Some geologists are of the opinion that the origin of the placer gold is from the reefs formed by the Homestake ledge in the Cambrian Sea. Other geologists consider that the gold was chemically precipitated by the action of the sulphides of iron and therefore not a true detrital deposit. A reason for this conclusion lies in the fact that the matrix of the auriferous conglomerate is pyrite rather than quartz; also that the gold occurs along fracture planes stained by iron oxides.

Homestake District: The Homestake belt is the most impor-

tant field in the Black Hills. It has been a steady producer of gold for many years. The Homestake ore bodies occur in the Algonkian slates which are for the most part of sedimentary origin. One variety has however been recognized as a metamorphosed igneous rock and catalogued as an amphibolite because amphibole is the most prominent constituent. The amphibolites occur as dikes or irregular masses in the other Algonkian rocks. The associated

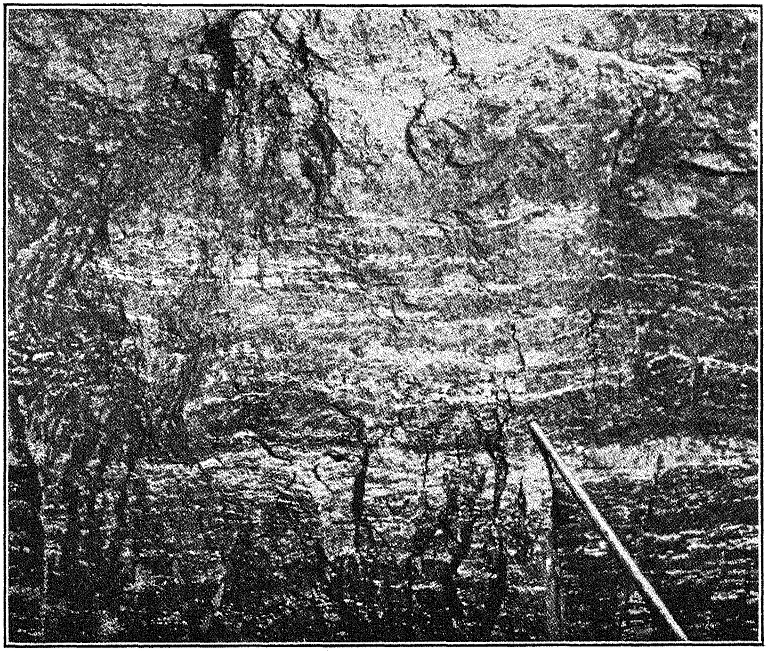


FIG. 45.—Banded siliceous ore in No. 2 shaft Union mine, Black Hills district, South Dakota, showing preservation of sedimentary bedding in the ore, the banding being continuous with the inclosing stratified rocks. (*After J. D. Irving, U. S. Geological Survey.*)

metamorphosed sediments are quartzites, quartz-schists, mica-schists, phyllites and graphitic, garnetiferous and chloritic slates.

More recent eruptives cut through all these rocks as well as the ore bodies themselves. The later eruptives are of two types. (1) A rhyolite porphyry, which is by far the most common rock. It not only cuts through the Algonkian terranes but spreads out in sheets or sills in the nearly horizontal strata of the overlying Cambrian series. (2) The second eruptive is a trachytoid phono-

lite which appears at the 800-ft. level of the Homestake mine and is a common rock in various parts of the northern Black Hills (Fig. 45).

According to J. D. Irving, the ores of the Homestake zone are poorly defined masses of rock sufficiently impregnated with gold to pay for working, but otherwise hardly to be distinguished from the country rock in which they occur. They are singularly barren of the usual ore minerals. The gold occurs in so finely divided a state that the particles are invisible even with a magnifying glass. Leaf gold has, however, been found but without evidence of crystalline structure. Pyrite and arsenopyrite are the only other metallic minerals present. The former is more abundant.

Quartz is the most abundant gangue mineral. It occurs in veins or lens-shaped masses often of considerable size and of several different periods of formation. Calcite and dolomite are also present as gangue minerals usually of secondary origin, but not universally present.

Origin of The Homestake Ores: There is no definite evidence as to the source of the gold and pyrite. Irving considers them to have been leached from the rocks at some distance below the surface by percolating waters and to have been precipitated in contact with graphitic matter and possibly also with original pyrite, present in the slates.

A second period of mineralization came after the later intrusion of the rhyolite porphyry, followed the same general channels and deposited the gold and pyrite. This intrusive did not stop at the Cambrian contact, but continued on through cracks and fissures into the Cambrian rocks and deposited gold and pyrite abundantly in the basal conglomerate of the Cambrian series and in the calcareous terranes immediately overlying the outcrop of the Homestake belt. In the conglomerate, wolframite replaces somewhat, the pyrite but there is no evidence of pneumatolytic action.

The secondary enrichment of the ores by surface leaching has been of relatively small importance. There is little evidence of decrease in value of ore with depth. In fact the size of the ore body appears to be increasing rather than decreasing with descent. The ore as a whole averages between \$5 and \$6 per ton.

According to J. D. Irving, the ore occurs in three distinct varieties. (1) *Banded ore*: That is, ore wherein the mineralization has not been accompanied by distortion of the original structures of the rock. (2) *Contorted ore*: That is, ore where the original

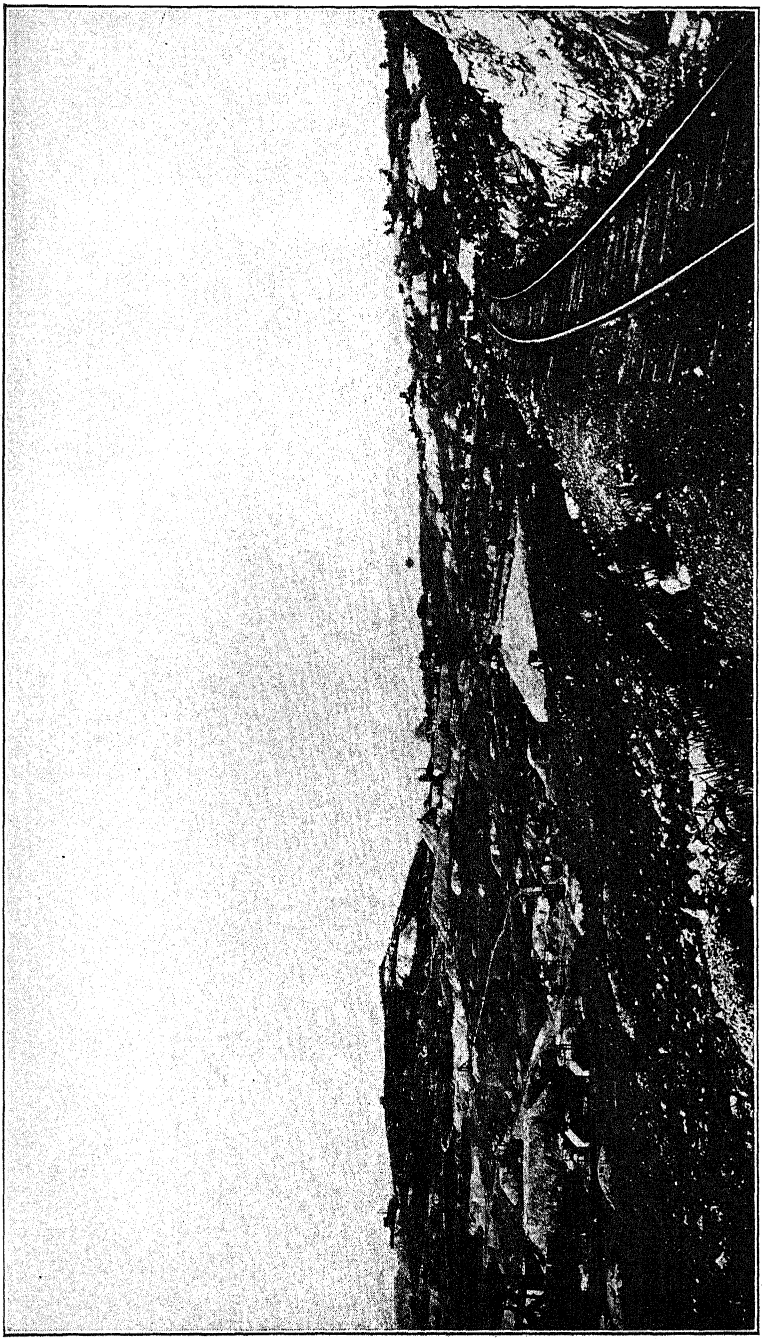


FIG. 46 —General view of Cripple Creek district, Colorado. The outcrop on the right is phonolite. (*By Permission of the Macmillan Company, from Ries' Economic Geology.*)

rock has undergone very great distortion. (3) *Massive ore:* Where few, if any, traces of either the original structure or the original constituents of the Algonkian rocks can be observed.

Cordilleran Region.—This vast area stretches through British Columbia on the north southward to Mexico and includes practically all States traversed by the Rocky Mountains. Its best development is in Colorado. Each of these western States is subdivided into fields and districts, and each is worthy of a detailed description but only a few of the most important fields are considered.

Cripple Creek. This district is situated 10 or 12 miles from Pikes Peak, Colorado, but in the foot hills of the same mountain

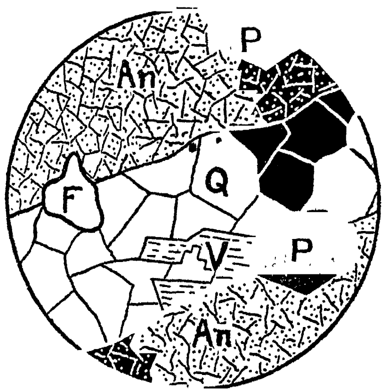


FIG. 47.—Small vein of andesitic breccia, Independence mine, Cripple Creek, Colorado. *An*, Andesitic breccia; *P*, pyrite; *F*, fluorite; *Q*, quartz; *V*, valencianite. (*After W. Lindgren, U. S. Geological Survey.*)

mass. The field is the most important as a gold producer in the Cordilleran belt. Its importance is testified to by the fact that it has already produced more than $200,000,000 in gold. It is essentially a gold field for the ore contains from 1 to 10 oz. of silver per ton.

The district consists of a series of highly metamorphosed mica schists bearing sillimanite, of pre-Cambrian age; the Pikes Peak granite, characterized by its microcline; the Cripple Creek granite also bearing microcline; and the Spring Creek granite which carries the commonest of the feldspars, orthoclase. In the metamorphics there also appear some differentiation products of an olivine-syenite magma. The volcanics of the area consist largely

of tuffs and breccias of Tertiary age. These are cut by dikes of phonolite, latite-phonolite, syenite, dolorite, and even the more basic rocks. (See Fig. 46.)

The ore bodies occur in two forms. (1) Lodes or veins, and (2) irregular replacement deposits. The veins are exceedingly narrow fissures incompletely filled. They are essentially in the volcanics and present a radical appearance. They are short and nearly vertical (Fig. 47). Some of the most productive fissures have been only a few hundred feet in length. In fact the entire field is circular in form with a radius of 2 or 3 miles.

The lodes may occur in both the eruptives and the irruptives.

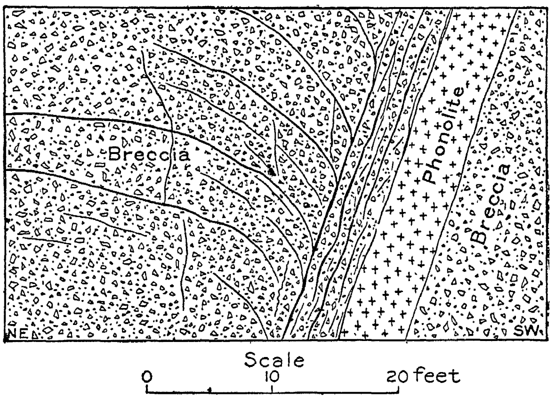


FIG. 48.—Sheeted zone and flats of the Apex vein, Ajax mine, Cripple Creek district, Colorado. (*After W. Lindgren and F. L. Ransome, U. S. Geological Survey.*)

In the former case they favor the breccias and in the latter the granites, as shown in Fig. 48. The fissures seem to have been formed by compressive stresses associated with the cooling igneous rocks. The fissures are particularly small and narrow and may occur in any rock in the series. (See Fig. 49.)

The replacement deposits usually occur in the granite. The principal gold ore is the telluride, petzite or calaverite which upon roasting brings the gold to the surface forming beautiful museum specimens. Pyrite is associated with the tellurides. Near the surface and in the oxidized zone in general the gold appears as brown, spongy gold while the tellurium has been converted into tellurites.

The common gangue minerals are quartz, fluorite and dolomite

with the sulphides of lead, zinc, antimony and molybdenum sparingly present. The ores were deposited from hot alkaline solutions. Fluorine was an important mineralizer. The rich telluride ore is shipped to Pueblo for smelting, while the lower grades are chlorinated or cyanided at the mines (Fig. 50). The banner production of this small area was reached in 1900 when an output of more than $18,000,000 was credited to the district, but the output has since declined to nearly $10,000,000 per annum.

San Juan District: The San Juan mining belt covers a large

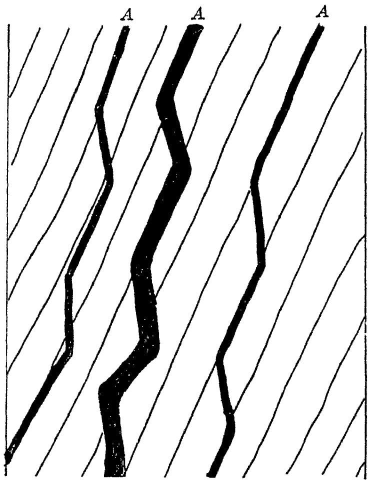


FIG. 49.—Section in the Victor, Smuggler Lee, and Buena Vista mines, Cripple Creek district, Colorado, showing the parallel ore bodies *A*. (*After Penrose.*)

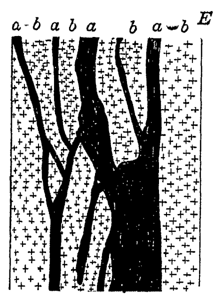


FIG. 50.—Section showing the forms of the veins in the Blue Bird mine, Cripple Creek district, Colorado. *a*, Ore; *b*, country rock. (*After Penrose.*)

area of mountainous territory in the southwestern part of Colorado. It embraces the counties of Dolores, Hinsdale, La Plata, Ouray, San Juan and San Miguel. The continental divide traverses the area with several peaks surpassing 14,000 ft. in altitude. The base of the geological series is Archean. The overlying Tertiary sedimentaries are capped with andesites, diabases, diorites, etc. Masses of rock composed of volcanic ejectamenta are not infrequent. Many V-shaped valleys of incision traverse the area. The whole field presents the appearance of a deeply cut volcanic plateau.

Telluride District: In the vicinity of Telluride there is a very interesting development of veins. The Smuggler vein is very persistent. It is definitely known that it extends four miles across the high divide that separates the Marshall basin from the valleys of Cañon Creek. Many of the veins consist of closely spaced fissures filled with ore. The pay portion rarely comprises the entire vein but rather forms a narrow strip following either the hanging wall or the footwall. The gold is often encased in pyrite and chalcopyrite with quartz gangue. The silver is in the galenite and freibergite, but the double sulphides of silver with antimony and arsenic, as polybasite, stephanite and proustite are known. According to F. L. Ransome the downward percolation of meteoric waters dissolved the alkalis from the andesites and rhyolites as sulphides. These solutions rose in temperature as they approached the magma and became charged with sulphuric and carbonic acids derived from volcanic sources. These acids gathered the metals and their gangue minerals from the more basic material and while penetrating the open spaces of the fissured zone, deposited the metals and gangue minerals at higher altitudes. The carbonates were deposited upon the walls of the fissures while the gold, to some extent, penetrated the walls.

Silverton: The Silverton district lies to the east of the Telluride. The Tertiary volcanics are separated from the Carboniferous terranes by a conglomerate. According to H. Ries, the ore depoits fall into three classes. (1) Lodes, which include most of the known productive deposits, (2) stocks, which include most of the ore bodies formally worked on Red Mountain, and (3) metasomatic replacements, which comprise a few deposits in the limestones or rhyolites.

The lodes occur in all terranes from the pre-Cambrian to the Tertiary irruptives.

The Tertiary fissuring is most pronounced in a northeast and southwest direction. The lodes are simple fissure veins. Sometimes these veins bear both native gold and silver. The gold is often encased in chalcopyrite and the silver in galenite, tetrahedrite and enargite. The common gangue minerals are quartz and calcite. The ores were deposited from hot ascending solutions with depth of origin unknown.

Ouray District: The Ouray district surrounds the picturesque city of Ouray. The terranes comprise limestones, conglomerates quartzites, sandstones and shales overlain by Tertiary volcanics.

Fissure veins are the most pronounced and persistent type of ore deposits in the district. Some of these may be traced for more than a mile along the line of their outcrop. Sometimes they reach a width of 75 to 100 ft. and are well mineralized throughout. Much free gold occurs in the Camp Bird, Revenue Tunnel, Atlas and Torpedo-Eclipse mines. Samples from the latter mine have assayed over $50,000 per ton. The ore is often associated with tellurium also encased in chalcopyrite with a gangue of country rock and clay.

Quartz, calcite, fluorite and barite are common gangue minerals. The silver occurs in part native, in part with galenite and tetrahedrite and in part as stephanite. Less important replacement deposits occur in the quartzites, sandstones and limestones. These deposits in the sandstones are more or less irregular but in the limestones they occur as broad flat ore bodies associated with the fissure veins that penetrate the limestones.

The fissuring appears to be late Tertiary and the mineralization in some period later than the introduction of the volcanics.

Georgetown District: This district is in the Continental Range in Clear Creek County, about 50 miles west of Denver. The base of the Geological series consists of pre-Cambrian schists of sedimentary origin which are overlain by highly metamorphosed schistose rocks of igneous origin. This series of terranes was later penetrated by both acid and basic intrusives. The latest irruptives of probably late Cretaceous or Tertiary age, consist of porphyry dikes. These porphyries are of special interest because they stretch in a northeasterly and southwesterly direction nearly the entire length of the state. The lodes occur in fissure veins that cut the pre-Cambrian schistose rocks.

Auriferous pyrite with a quartz gangue predominates in the neighborhood of Georgetown. These veins may or may not bear silver. At the Silver Plume mine much fine-grained argentiferous galenite is encountered. At Idaho Springs the prevailing ore is an argentiferous galenite-sphalerite which contains but little gold. According to J. E. Spurr, descending meteoric waters have effected from the wall rock a mixture of quartz, calcite, kaolin and sericite. The walls of the fissure appear to have been the source of the gangue minerals, while the gold and silver were contributed to the veins by magmatic waters.

The gold-bearing veins appear at the lower level and the silver at the higher altitudes in this deeply incised region. The former

FIG. 51.—Goldfield, Nevada, from Mira Mountains. The principal mines lie beyond the basalt cuffed hill in the right foreground. The sharp peak in Columbia Mountains. (*After F. L. Ransome, U. S. Geological Survey.*)

metal therefore is found most abundantly in what may be only the lower portions of the argentiferous veins.

Sierra Region: Goldfield is situated in the southwestern part of Nevada in Esmeralda County. (See Fig. 51.) According to F. L. Ransome the base of the geological series consists of pre-Cambrian metamorphics. These suffered denudation until the close of the Jurassic Age, when the intrusive alaskite and granite were introduced. This was followed in Tertiary time by eruptives ranging from rhyolite to basalt. The dacite is the most productive extrusive, while some rich ores are found in the andesites. The ore bodies are noted for their remarkable richness and irregularity. The fissures are usually irregular, small and intersecting fracture-flows passing into brecciated material. Faulting seems to be absent. After the dacite lode solidified unknown stresses developed this intricate fracturing. The ores are free gold and auriferous pyrite associated with silver, copper, antimony, arsenic, bismuth and tellurium minerals. Magmatic waters contributed the gold to the fissures. These ascending solutions bore H_2S and CO_2 Near the surface the hydrogen sulphide was in part oxidized to H_2SO_4. The downward trend of these acid solutions through the shattered dacites and andesites and their subsequent mingling with ascending solutions caused the precipitation of their metallic contents. The gold would be precipitated by alkaline carbonates, as native gold. The freshly formed pyrite would serve as a reducing agent upon its encased gold. A second stage of fracturing and mineralization seems to have occurred in this field (Figs. 52 and 53).

Comstock Lode: The Comstock Lode is situated in the southwestern part of Nevada on the eastern flank of Mt. Davidson in the vicinity of Virginia City, Washoe County. The geology of this region has been a matter of much study on the part of able scientists like Becker, Von Richthofen, Hague and Iddings. Von Richthofen considered the ore body as filling a fissure on the contact between a syenite foot-wall and an eruptive propylite hanging wall (Fig. 54).

Clarence King considered that the vein filled a fissure between a syenite and the Tertiary eruptives poured out upon the flank of Mt. Davidson. Arnold Hague and J. P. Iddings, from an extensive study of the rock masses, concluded that the Comstock Lode occupies a line of faulting rocks of the Tertiary age and cannot be considered as a contact vein between two different rock masses.

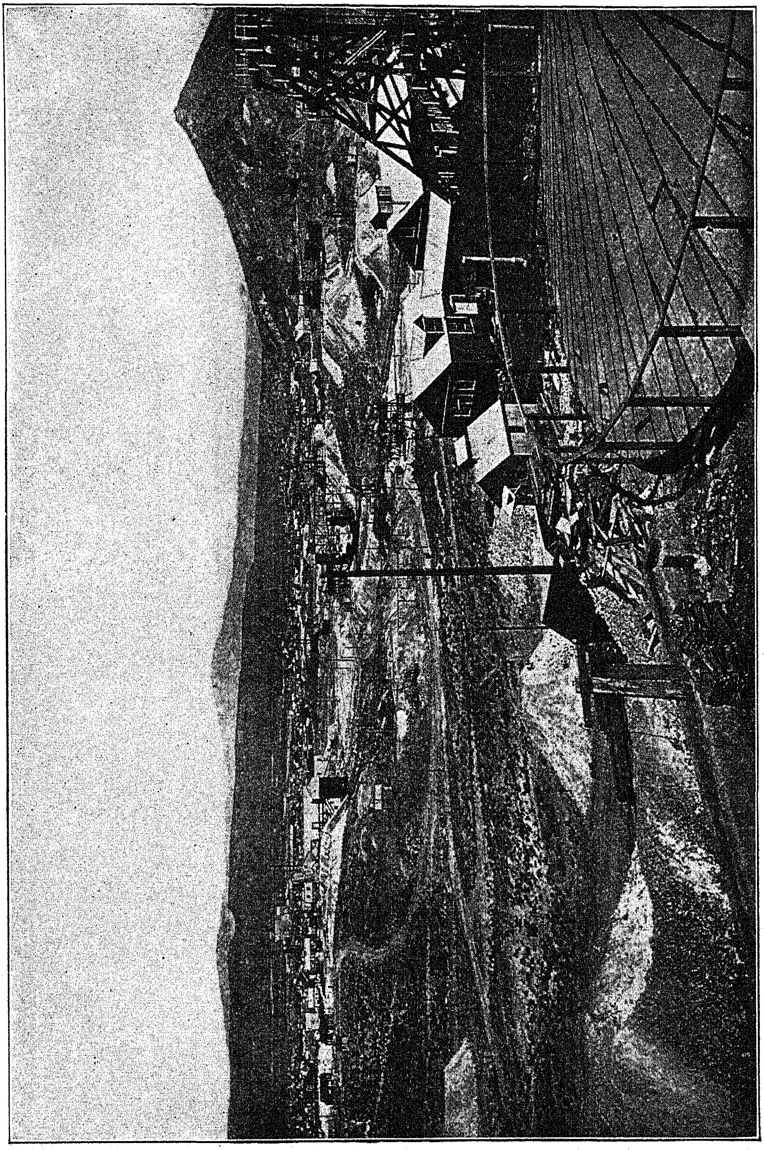


FIG. 52.—View from Florence Hill, Goldfield, Nevada, looking northwest. (*After F. L. Ransome, U. S. Geological Survey.*)

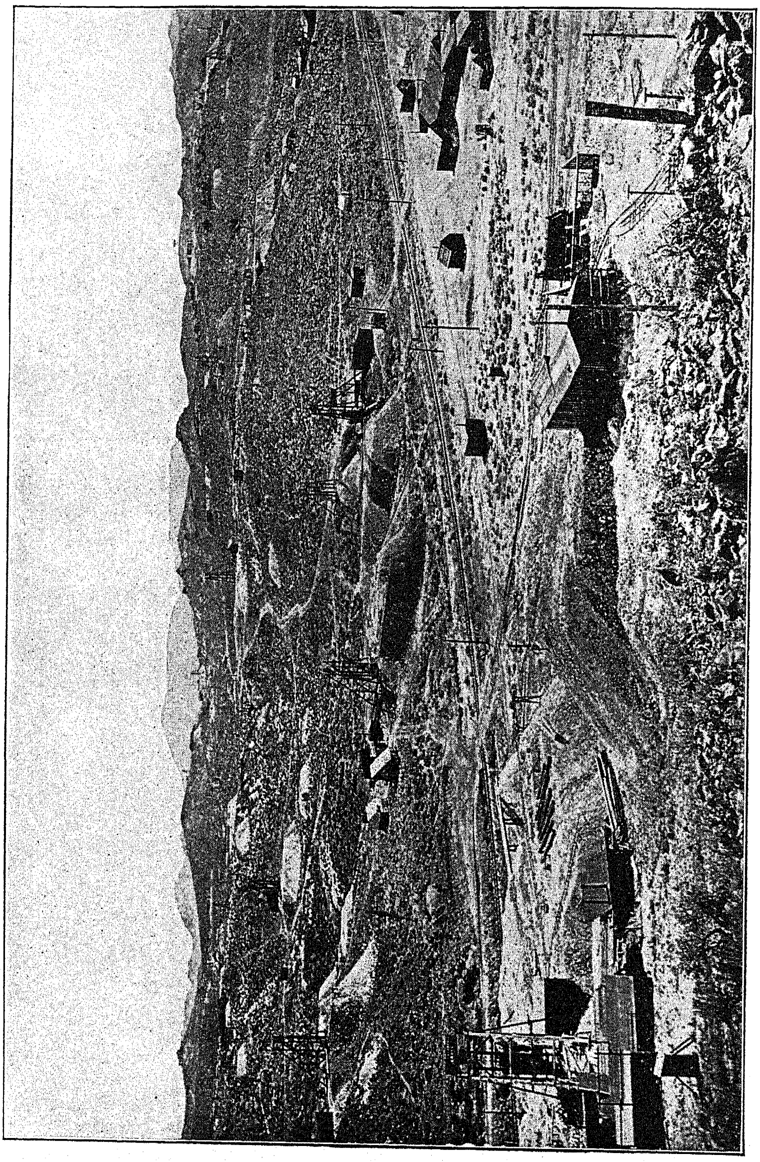


FIG. 53.—View from Florence Hill, Goldfield, Nevada, looking east. (*After F. L. Ransome, U. S. Geological Survey.*)

The vein itself is a true fissure vein about 4 miles long, and several hundred feet wide, branching in the upper portions, and faulted 3000 ft. in the center. The faults gradually die out as the ends of the veins are reached. The lode contains gold and silver and the chief gangue mineral is quartz. According to Von Richthofen, the ores and gangue minerals were brought up by ascending solutions. Fluorine, chlorine and sulphur were the agents of solution.

The ore occurs in bonanzas of remarkable richness. One of these bonanzas is said to have furnished $110,000,000 in gold and silver. The ores are marked also by great irregularity. Gold predominates over silver in the ratio of 3 : 2. The mine has yielded nearly $400,000,000 and is still a steady producer (Fig 55).

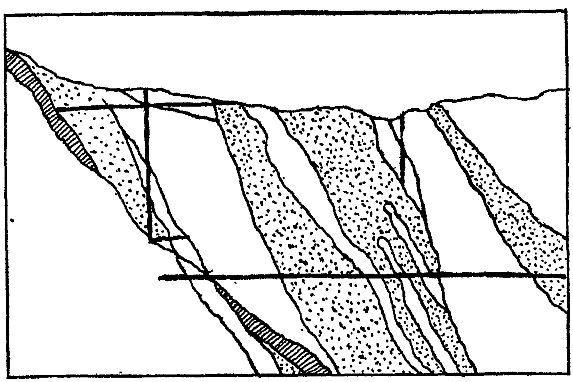


FIG. 54.—East-west section through the Comstock lode in Nevada showing the position of two of the ore bodies, and of the Sutro tunnel.

The Pacific Coast Region.—This belt extends along the Pacific coast from Lower California northward through California, Oregon, Washington and British Columbia. The California field is the most important of all for it furnishes an annual output of approximately $20,000,000. The belt is characterized by quartzose ores and auriferous sulphides. In the more northerly portion of the belt silver occurs with the gold and the auriferous sulphides are without free gold. The region is characterized by many placers which have been derived from the weathering of the upper portions of the quartz veins (Fig. 56).

The Mother Lode Belt: This belt comprises a large series of quartz veins stretching in a northerly and southerly direction for

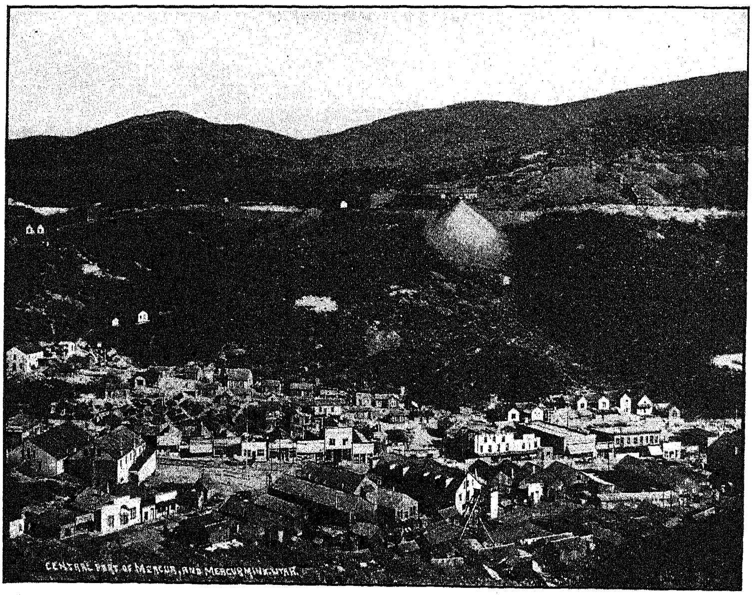


FIG. 55.—View of a portion of Mercur, Utah, and the Mercur mine. *(By permission of the Macmillan Company, from Ries' Economic Geology.)*

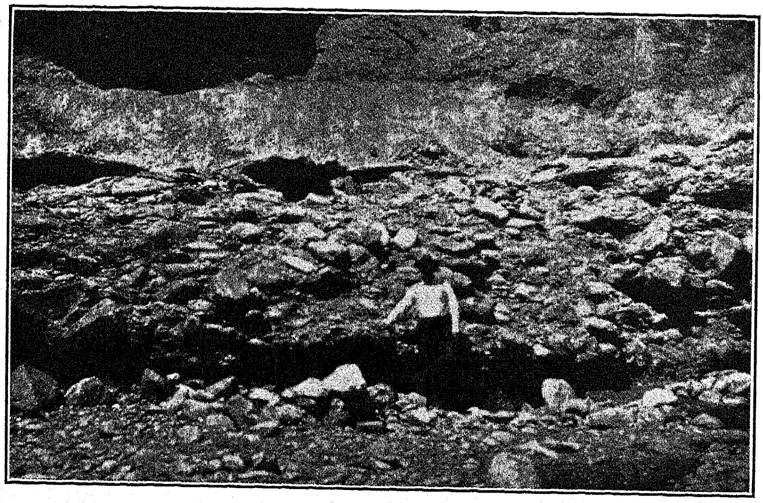


FIG. 56.—Lowest bed of coarse and bouldery gold-bearing gravel at Cherokee mine, Butte County, California. *(After W. Lindgren, U. S. Geological Survey.)*

113 miles. The mines are situated in Amador, Calaveras, El Dorado, Mariposa and Tuolumne Counties. These counties furnish three-fourths of the milling ores of the State. The average recovery per ton is much less than in other counties where the veins are smaller and richer. The average recovery from all the counties in the Mother Lode district is less than \$4 per ton while in Nevada County the amount exceeds \$10 in gold and silver per ton of ore mined.

One characteristic of the Mother Lode is the permanancy of the ore with increasing depth. In Amador County the mines are now 3500 ft. deep and the ore is as good as that found at the surface. The ores occur in fissure veins in steeply dipping slates and altered volcanics of Carboniferous and Jurassic age. The ores are found at so great a distance from the granitic rocks of the Sierra Nevadas that they are supposed to bear no genetic relation to them. The veins occur both in the slates and at their contact with diabase dikes. The veins show a remarkable extent and uniformity. In the tilted layers of the slate there lay planes of weakness which the mineral-bearing solutions followed. The chief gangue mineral is quartz, and the ore is native gold and auriferous pyrite.

Nevada County: The Grass Valley district of Nevada County still continues to be the leading quartz-mining section of the State. None of the other counties, even those of the famous Mother Lode, approach it in its production of gold. The deep mines of the county are yielding per annum about 2,000,000 tons of free milling ores and 500,000 tons of auriferous copper ores that are treated at the smelters. The veins are quartz and occur along the contact between a grano-diorite and diabase prophyry. They also cut the igneous rocks. Two systems of fissuring are known. The gold is either native or associated with metallic sulphides. The width of the vein seldom exceeds 3 ft. The lode ore occurs in well-defined bodies or pay shoots. W. Lindgren believes that the ores were leached out of the rock at a considerable depth and deposited by hot solutions while the wall rocks contained the rare metals in a disseminated condition.

The Alaska Field.—The region may be divided into: (1) The Sitka district; (2) the Juneau and Douglas Island district Northeast of Sitka; (3) the Fairbanks district in the central part of Alaska and; (4) the Seward Peninsula in the western part of Alaska, as shown in Fig. 57.

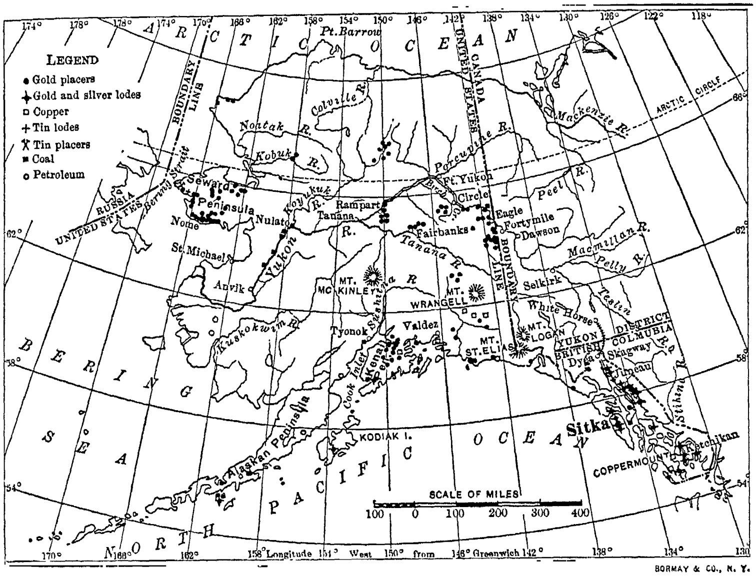


Fig. 57.—Map showing mineral deposits of Alaska. After Brooks. (*By permission of the Macmillan Company, from Ries' Economic Geology.*)

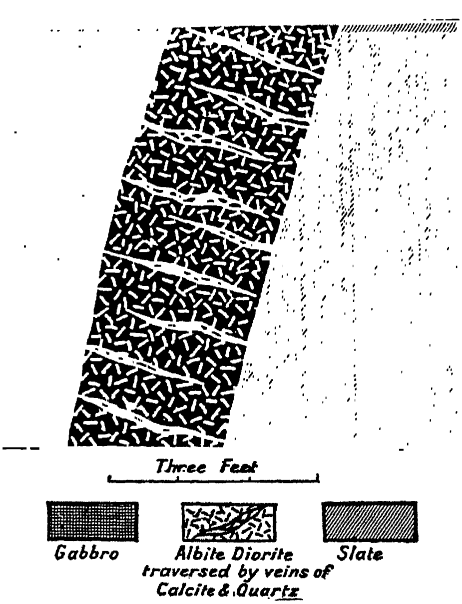


Fig. 58.—Gold ore in transverse veins in the Ready Bullion mine, Treadwell, Alaska. (*After A. C. Spencer, U. S. Geological Survey.*)

It is of interest to note that the United States paid $7,200,000 for the Alaskan territory. It was catalogued as the "white elephant" on the hands of the United States government. Yet the total gold brought out of Alaska exceeds $150,000,000 with an output in 1910 of $20,947,600 or nearly three times the amount paid for the territory.

The Lodes: Gold quartz lodes occur most abundantly along the coast, especially near Sitka and on Douglas Island. The ore bodies are dikes of diorite traversing black slates. The hanging wall of the ore body is a much altered intrusive greenstone and the foot wall is a black slate. (See Fig. 58.)

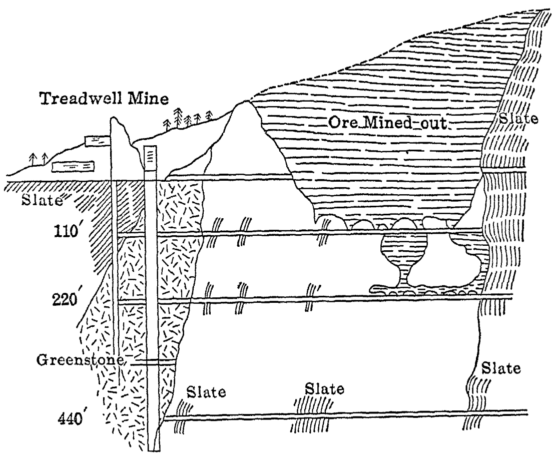


FIG. 59.—Section through the Alaska Treadwell mine, Douglas Island, near Juneau, Alaska.

Two sets of fractures at right angles to each other seem to have been incident to the epirogenic movements of the region. According to Spencer, the mineralization was caused by hot ascending solutions of magmatic origin. Secondary concentration is not in evidence. The actual depth to which the ores can be worked depends more upon the increased cost of mining at great depths than upon the exhaustion of the ore body. An almost continuous ore body has been developed for more than half a mile. (See Fig. 59.)

The Placers: Gold occurs most abundantly in Alaska in placers. The placer deposits of Seward Peninsula alone are about equal in area to those of California and approximately ten times

as large as those of the Klondike field which lies east of the International boundary. Mining in Klondike is said to have passed its zenith while the maximum yearly output of Seward Peninsula is still to be reached. The Klondike placers were discovered in 1896 and those on the Seward Peninsula in 1897.

According to A. H. Brooks, three conditions are usually operative in the formation of placers: (1) The occurrence of gold in bed rock to which erosion has access; (2) the separation of gold from bed rock by weathering or abrasion; and (3) the transportation, sorting and deposition of the weathered and eroded auriferous material.

Origin: In some parts of Europe, in the tropics and in the southern Appalachians some workable placers have been formed solely by the weathering of the bed rock in place. T. A. Rickard recognized placers in Australia that have been concentrated through the agency of the wind, the lighter material having been removed. In the formation of the true placers transportation, sorting, and deposition of material furnished by the weathering of the rocks are important agents. Uplift may revive the forces of erosion and render these agencies repeatedly effective, which results in the reconcentration of the alluvial gold.

The classification of placers should be based both upon origin and form. According to their origin there are three types of placers: (1) Residual; (2) sorted placers; and (3) re-sorted placers. The residual placers are those in which there has been no water transportation, the concentration of gold being due solely to rock weathering. The gold of the sorted placers is the result of transportation, sorting and deposition of auriferous material by water. Re-sorted placers are those in which the gold has passed through two or more cycles of erosion before its final deposition.

Residual placers are practically all of one type. Sorted placers may be subdivided into hillside, creek and gulch, river bar, gravel plain, bench and high bench deposits. Re-sorted placers may be divided into creek and gulch, beach and elevated beach deposits. Intermediate types may be found which belong to either one of the last two groups. Hillside placers occur on hill slopes and do not occupy any well-defined channels. They grade on the one hand into placers of residual origin and on the other into placers of the stream or gulch type. Creek and gulch placers occur both in material that has been assorted once and in that which has passed through several cycles of erosion.

Gold in the Placers: The gold has usually been deposited where the current of a stream has been checked. A broad basin above a steep-walled canyon is more likely to carry gold than the valley below the canyon, provided the bed rock source of the gold is above the basin. Coarse gold is more likely to be found at the head of a filled basin than near its outlet. The same holds true of a stream that debouches on a coastal plain which will deposit the coarse gold it may carry near the head of its delta.

A. J. Collier and F. L. Hess give the following classification of the placers in Seward Peninsula:

(1) Creek Placers: Gravel deposits in the beds and intermediate flood plains of small streams.

(2) Bench Placers: Gravel deposits in ancient stream channels and flood plains which stand from 50 to several hundred feet above the present streams.

(3) Hillside Placers: A group of gravel deposits intermediate between the creek and bench placers. Their bed rock is slightly above the creek bed and the surface topography shows no sign of benching.

(4) River-bar Placers: Placers on gravel flats in or adjacent to the beds of large streams.

(5) Gravel-plain Placers: Placers found in the gravels of the coastal or other lowland plains.

(6) Sea-beach Placers: Placers reconcentrated from the coastal plain gravels by the waves along the seashore.

(7) Ancient beach Placers: Deposits found on the coastal plains along a line of elevated beaches.

Klondike.—This important mining field lies a little to the east of the Alaskan boundary and in the valley of the Yukon. The auriferous gravels of the district occupy about one-tenth the area of those in Seward Peninsula. In fact the number of miles of creeks bearing placer gold in the Klondike has been catalogued as 50 in comparison with 750 on Seward Peninsula. The placers of such creeks as the Eldorado and Bonanza averaged richer than any deposits on Seward Peninsula. It was the exploitation of these almost fabulously rich and relatively shallow placers that the Klondike gold output went up with a bound, and it is their quick exhaustion that has caused so marked a decline in their annual yield. There are extensive deposits of lower grade gravels, but these are not likely to make the annual yield again equal to that of the banner year. (See Fig. 60.)

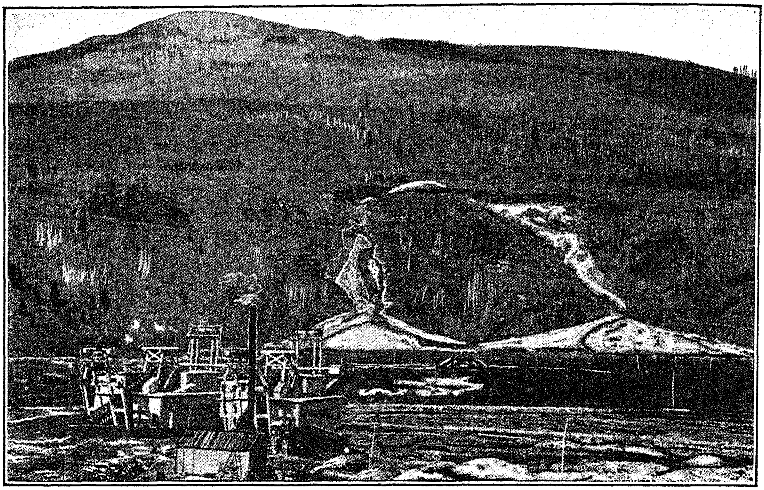


Fig. 60.—Dredges on No. 104 below, on Bonanza Creek, Yukon Territory, Hydraulic plant in operation on hill in the distance. (*After D. D. Cairnes, Canadian Geological Survey.*)

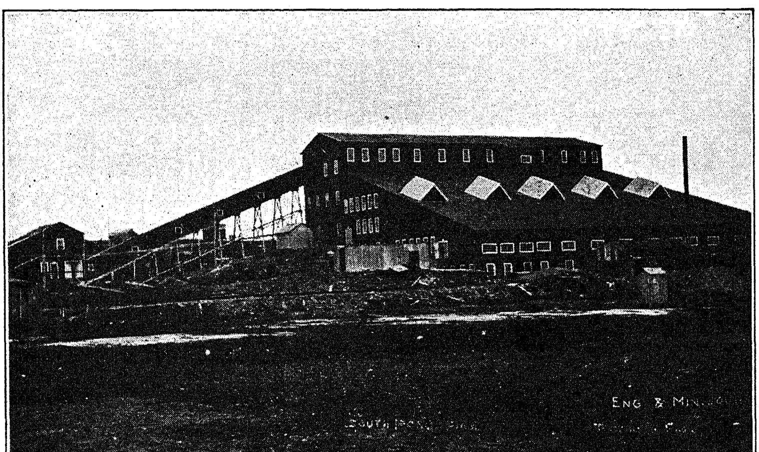


Fig. 61.—The Dome mill, Porcupine district, Ontario, for cyaniding gold. Showing inclined conveyor.

Porcupine.—The porcupine district represents a new field. It is situated in the northern part of Ontario. The most important counties thus far exploited are Doloro, Shaw, Tisdale and Whitney. In these four counties practically all of the ground has been staked. The Dome mines represent the pioneer work in this field. Within the first 100 ft. from the grass roots the company is said to have actually blocked out $8,000,000 of gold. The field bids fair to be a large producer for three reasons. (1) Its own native richness; (2) the great number of scattered free gold discoveries, and (3) the completion of the railroad to Porcupine during the summer of 1911. The geology of the district is represented by a series of pre-Cambrian metamorphics traversed

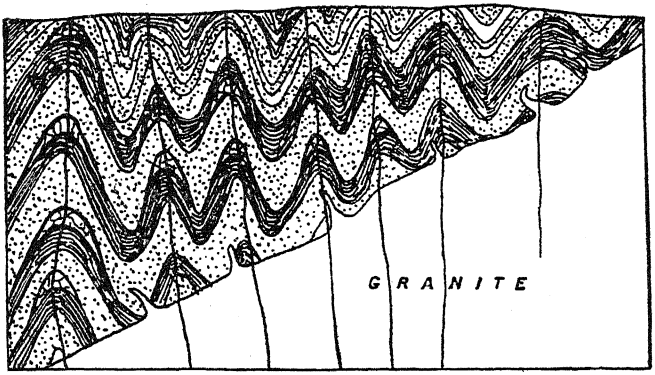


FIG. 62.—Structural arrangement of the Silurian slates and sandstones at Bendigo, Australia, in which the auriferous saddle-reefs are found. (*After Thomas and MacAlister's Geology of Ore Deposits.*)

by a diabase of post-middle Huronian age. The gold is free milling and the most important gangue is quartz. (See Fig. 61.)

The Geological Horizon of Gold: Gold may be found in small quantities in nearly all, if not all, geological formations. It is especially abundant in the pre-Cambrian, Ordovician, Cretaceous and Tertiary formations, that is, in general, in the older rocks, but the last two are among the younger formations. The Silurian Devonian and Carboniferous terranes are not known to carry gold in paying quantities in the United States, but in British Columbia gold occurs in the Carboniferous strata. However it is possible that some of the gold-bearing rocks of the Appalachian belt are as late as the Carboniferous, but in the main they are Cambrian and Ordovician. (See Fig. 62.)

Methods of Placer Mining.—In the early history of placer mining, only a few feet of earth next to the bed rock and the upper surface of the bed rock itself was panned, washed or sluiced, for the richest portion of the entire placer lies near the bed rock. The earliest method of reclaiming the gold was by panning. This was followed by the rocker, the long-tom and sluice-box, the ground sluice, drift mining, the monitor, the hydraulic elevator and the electric dredge. In the hydraulic process, the entire placer is washed by carrying the auriferous gravel into sluices across which riffles are placed for the extraction of the gold. In

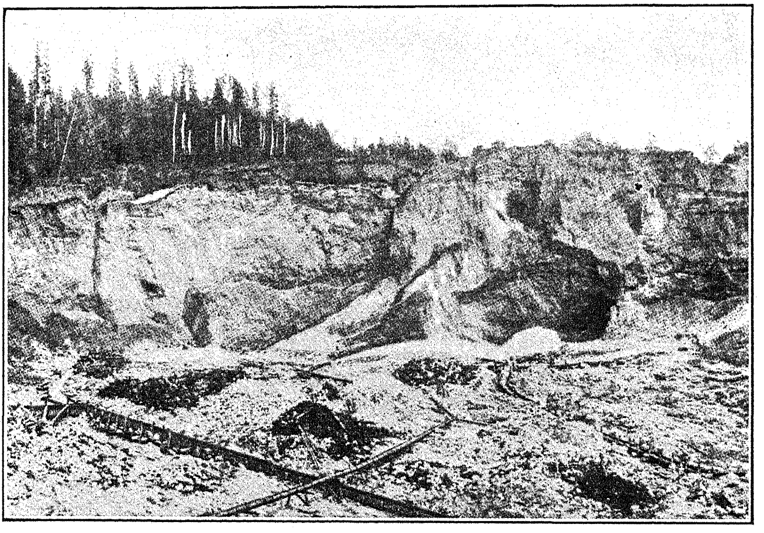


FIG. 63.—American Hill Placer mine, Elk City, Idaho. (*After W. Lindgren, U. S. Geological, Survey.*)

some cases mercury is placed upon the riffles and the free gold unites with the mercury in the formation of an amalgam. (See Fig. 63.)

More than one-fourth of the gold mined in California at present is obtained through dredging, mostly from ground previously mined. The electric dredge has solved the problem of mining the gravels below the water level and in rapidly flowing streams (Fig. 64).

The chief difficulty of placer mining in the Klondike is the permanently frozen ground, which has led to certain peculiarities in

the method adopted. Every yard of the gravel which is sluiced must first be thawed either by artificial means or by exposing it to the rays of the summer sun, after stripping off the muck that overlies the auriferous gravels. It is impossible to work the frozen

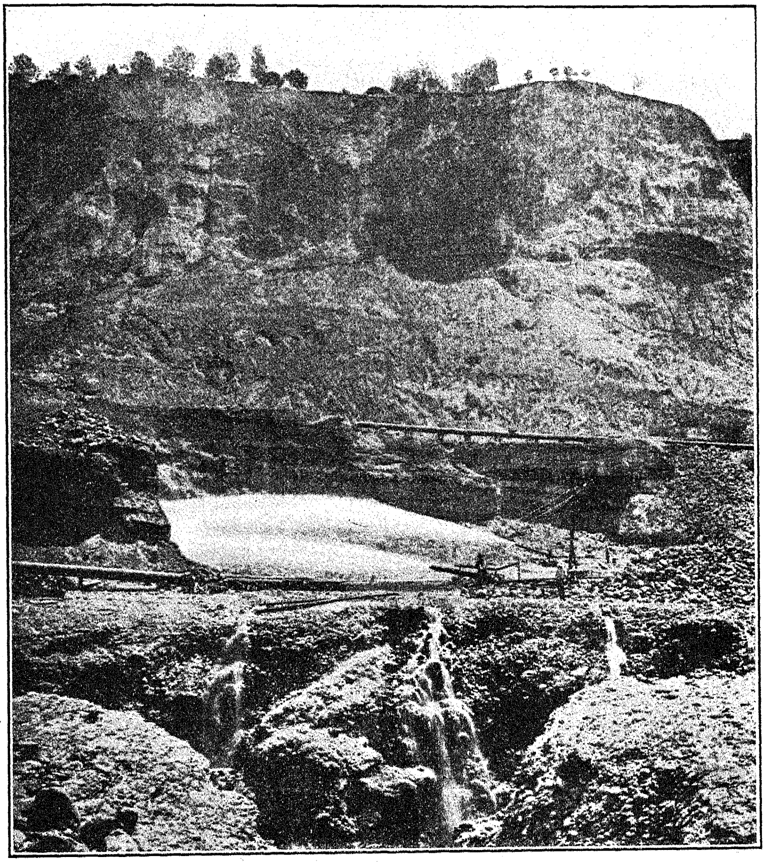


FIG. 64.—Hydraulic mine at Cherokee; Butte County, California. (*After J. S. Diller, U. S. Geological Survey.*)

ground with pick and spade, or even with explosives to loosen the gravel.

Steam thawing is the most efficient method now in use. Iron pipes, 4 to 6 ft. in length, tipped with steel nozzles, are inserted into the gravel and then steam is forced through them at a pressure of about 120 lb. per square inch. These pipes are known as

points, one point being inserted in each square yard, and driven gradually by a hammer. Each point will thaw from 2 to 5 cu. yd. of gravel per day.

The washing of the gravel is usually done by sluices. These are long wooden troughs made in 12-ft. lengths, and about 10 in. broad. The bottom is lined with wooden riffles consisting generally of longitudinal bars, by which the gold and heavy minerals are caught. The common sluice head has a fall of 8 in. in the 12 ft. and has a capacity of 120 cu. ft. per minute.

Water is very scarce in some districts and must be used economically. In some instances the water is conducted for long distances in sluice boxes. In case the valley is wide and the pay streak is on the opposite side of the valley from the stream, the water is raised by centrifugal pumps to a height of 30 or 40 ft. and conveyed across the valley by a long flume. In the final wash-up by which the gold is recovered from the sluice boxes the riffles are removed and a copious stream of water sent down the sluice which carries away the fine gravel and leaves the gold and the heavy black sand that accompanies it. When dry, the sand is removed by blowers.

The placer mining upon creeks and hillsides is somewhat different. On a creek a shaft is sunk down to bed rock. Four lateral drifts are driven from the shaft along the surface of the bed rock, and opened out in a fan-like manner, to the limits of the claim. The outermost portions are worked first, and the ground is mined toward the shaft, or retreating. During the retreat the rock and the overlying muck are allowed to cave and settle down to the bed rock. Timbering is thus entirely avoided. The frozen grounds require no support, and chambers often 100 ft. square are found covered by an icy roof of muck.

Amalgamation.—For amalgamation, the ore must be free milling, that is, not require roasting before the gold or silver will unite directly with mercury. The ore is first crushed to a size varying from 1 to 2 in. in diameter. It then passes with water to the stamps where it is reduced to an impalpable pulp. It is then carried over plates covered with silver-plated amalgamated copper. From these plates it passes directly to concentrating tables or Frue vanners where the sulphides are separated by their higher specific gravity and shipped direct to the smelter. The tailings comprise that portion that goes into the streams as waste. The plates were formerly made of copper, but the copper

did not catch all the gold. The silver-plated amalgamated copper plate, which has taken its place, saves 15 per cent. more gold than the old copper plates, and the gold caught above the blankets is 16.72 per cent. greater. The old copper plates were inefficient for three reasons: (1) They tarnish quickly, and the amalgam passes over the tarnished surface. This has to be removed by washing the plates with KCN solution. (2) The amalgam is loosened from the plates by the washing with KCN and mechanically lost. (3) The chemical loss of amalgam by the same agent through solution is great. The total loss of gold

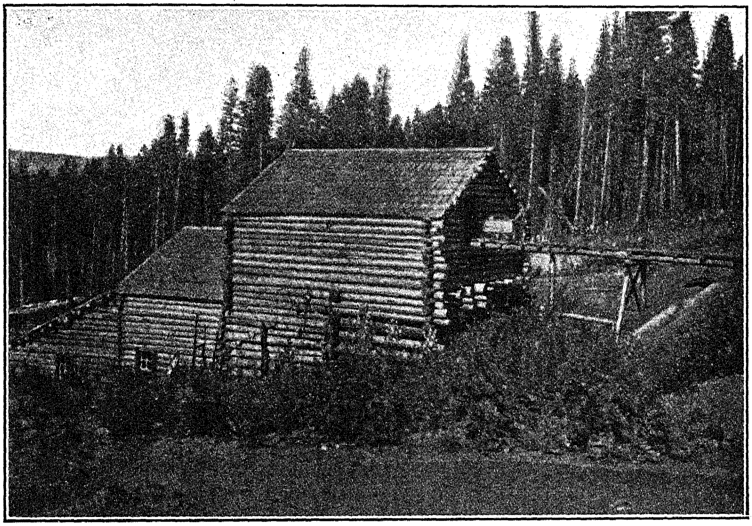


FIG. 65.—Iron Crown quartz mill, Newsome Creek, Idaho. (*After W. Lindgren, U. S. Geological Survey.*)

is frequently 10 per cent., but by improved methods in washing and general treatment of the ore 95 to 98 per cent. of the total gold content is recovered. (See Fig. 65.)

Cyanide Process.—The ore is crushed and treated with a solution of KCN, when a double cyanide of gold and potassium is obtained. The double cyanide is often catalogued $KAu(CN)_2$, and from this solution the gold is precipitated by metallic zinc. One-half pound of zinc is required per ton of solution, the total cost then per ton for precipitation is 12 cents; and a profit can be obtained where only 3 grains of gold exist in a ton of solution.

The zinc may be used in the form of zinc dust, shavings, granulated zinc or sheet zinc, but the zinc dust is generally preferred because it exposes a larger percentage of the surface to the action of the solution. The following equation shows the reaction that might take place.

$$2KAu(CN)_2 + Zn = K_2Zn(CN)_4 + 2Au.$$

The process is applicable to certain free milling ores, to refractory ores, but was designed especially for the treatment of tailings which were allowed to flow to waste for many years. Many western plants now have their cyanide plant in connection with their amalgamation plant.

Chlorination Process.—This is not applicable to free milling ores carrying nuggets, but to sulphides carrying large quantities of free gold. The cre is crushed, roasted, weighed and then charged into barrels with 18 tons capacity, $6\frac{1}{2}$ ft. in diameter and 15 ft. long. Nascent chlorine is the solvent. The solution from the barrels passes to a filter tank for the removal of the sand. From the filter tank it passes to a settling tank for the removal of the fine particles held in suspension; from the settling tank it passes to the precipitation tank, in which is placed zinc ribbons, scrap zinc, or zinc dust. Hydrogen sulphide is sometimes passed into these tanks, and the resulting gold is reasonably pure, but charcoal is the most efficient reducing agent, and the gold obtained is 0.995 fine.

$$2AuCl_3 + 6FeSO_4 = 2Au + Fe_2Cl_6 + 2Fe_2(3O_4)_3.$$

Reduction by Sodium Thiosulphate.—A solution of $Na_2S_2O_3$ for the extraction of gold and silver has far greater solvent power than potassium cyanide and is non-toxic in its physiological effect. It can be prepared in large quantities at low price according to the following formula:

2 parts. $Na_2S_2O_3$; 2 parts. CH_3CO_2Na; 3/4 part. $FeCl_3$; add 10 times the volume of H_2O. This will dissolve from 15 to 20 times as much gold in 10 hours as a 2 per cent. solution of potassium cyanide, 2 per cent. being the maximum strength allowable in cyanide solutions. The gold can be recovered from the solution by zinc shavings, zinc dust, zinc ribbons, and by electrolysis. The cost of treatment by this process is estimated at \$2.75 per ton.

Reduction by Electrolysis.—Gold is readily separated by electrolysis from its various solutions, and in this method of treat-

ment, silver-plated amalgamated copper plates are not as effective as the older type. Copper, iron and lead plates are used in the order of their efficiency. Copper is more effective than iron and iron is more effective than lead. The silver-plated amalgamated copper plates are profitable only when a current of low density is employed.

Uses of Gold.—Gold is used in the various arts and industries, for coinage; for jewlery, spectacles, and pen making; in dentistry, and in chemical and photographic work. The beaten gold leaf is used for gilded letters of signs, for lettering on book bindings, for book edges, for mirror frames and picture frames, for gilding metals. Gold dust is used in the moulding of furniture or room decoration. The Japanese use gold largely in the manufacture of lacquers. Gold is drawn into wire and used for gold lace, and other decorations.

It may be of interest to know the relative proportion that enters into these different fields: For coinage, 44 per cent.; for jewlery, 24 per cent.; for exportation, 10 per cent.; watch cases, 10 per cent.; gold leaf, 2 1/2 per cent.; watch chains, 1 3/4 per cent.; pens, dentistry and mechanical work, 1 1/4 per cent.; for gold plate, 3/4 per cent. All these uses may be catalogued as its use in American arts and industries. This will give for industries 40 per cent., coinage 44 per cent.; exportation 10 per cent. These are based directly upon the coining value of the metal, or $20.67 per Troy ounce.

SILVER: ITS PROPERTIES, SOURCE AND USES

Properties.—Silver, symbol Ag, is known as the white metal. It is pure white and susceptible of very high polish. When it is in the form of a powder, it has a gray or earthy appearance. It is malleable, ductile, and sectile, so that it can be rolled or hammered into thin sheets and readily drawn out into extremely fine wire. It is the best conductor of electricity known and its conductivity is increased by the process of annealing. It is harder than gold, and softer than copper. It is, therefore, alloyed with copper in coinage. For United States coinage the standard is nine parts of silver to one part of copper. Its specific gravity is 10.50 when cast, and 10.57 when struck by the die in coinage. Its melting point is 955° C., and its atomic weight is 107.88.

Ores of the Metal.—Silver occurs native containing small quantities of gold, copper, iron, cobalt and antimony. It occurs

as threads or plates through the reduction of other ores of silver, or it may occur deposited as a film over other minerals or rocks, as copper or carboniferous shale. The other ores of silver are as follows:

Argentite, Ag_2S, containing 87.1 per cent. silver, the only black and sectile sulphide of silver, the most unstable of all the sulphides of the commoner metals; *pyrargyrite*, $3Ag_2S,Sb_2S_3$, containing 59.9 per cent. silver; *stephanite*, $5Ag_2S,Sb_2S_3$, containing 68.5 per cent. silver; *polybasite*, $9Ag_2S,Sb_2S_3$, containing 75.6 per cent. silver; *proustite*, $3Ag_2S,As_2S_3$, containing 65.4 per cent. silver.

Silver occurs also in association with copper minerals; as tetrahedrite, $4Cu_2S,Sb_2S_3$; although no silver is present in the formula, samples of this ore have given 500 lb. of silver to the ton; tennantite, $4Cu_2S,As_2S_3$, sometimes bears silver.

Silver occurs abundantly in argentiferous galenite. All galenite is more or less argentiferous, but the finely crystalline variety contains more silver than the coarse mineral. Silver occurs with tellurium in hessite, Ag_2Te, containing 63.3 per cent. of silver; in petzite, displacing gold, for petzite is a telluride of gold $(Ag,Au)_2$-Te. It occurs in combination with selenium in naumanite, PbSe,-$13Ag_2Se$, and also as the selenide alone, Ag_2Se. It occurs with bismuth, copper and mercury, but perhaps more important as the amalgam. This implies varying combinations of silver and mercury. Instead of the direct union in the line of atomic weights, seems to unite with mercury in almost all proportions. The amalgam contains 27.5 per cent. to 95.8 per cent. of silver.

Silver occurs again in combination with the halogens. The most important haloids of silver are: Cerargyrite, AgCl, with 75.3 per cent. of silver; embolite, 3AgCl,AgBr, containing 66.9 per cent. silver; bromyrite, AgBr, containing 57.4 per cent. of silver; iodyrite, AgI, containing 45.2 per cent. silver. All of these haloid minerals are soft and sectile.

Silver is very widely distributed in nature. It is produced by practically all countries of the world, although many of them produce only a small quanity of the metal. It has been observed as a natural constituent of igneous rocks. It has been detected in common salt, in sea weed, in sea water, and in corals. In most cases native silver is of secondary origin, the metal being derived from the reduction of the sulphides and antimonides of silver. Organic matter is a common reducing agent effecting the precipi-

tation of silver in a metallic state. Pyrite, chalcopyrite, and many other sulphides, reduce silver solutions readily to the metallic state. According to Dr. F. W. Clarke, the metal will be precipitated by any reaction in which nascent hydrogen is brought in contact with a silver solution. The nature of silver solutions in metaliferous veins is not positively known. Silver sulphate is readily formed by the oxidation of the sulphide, and that will be transformed into the chloride by percolating chlorine-bearing waters. The antimonides, arsenides, and selenides of silver are rarer minerals, and are of only small importance in the production of the metal. These by subsequent enrichment might become of commercial importance.

Character of Ore Bodies.—At Butte, Montana, the ore occurs as native silver, with galenite in veins of quartz-bearing manganese. These are true fissure veins cutting irruptive granite. At Granite Mountain, 20 miles from Butte, the ore is ruby silver associated with gold in a true fissure vein cutting a gray granite. At Neihart, the ore occurs in veins in gneiss and other igneous rocks, mostly as replacement deposits which have been subsequently fractured and secondarily enriched. Argentiferous galenite is common in Montana as contact deposits between porphyritic igneous rocks and Carboniferous limestone.

In the production of silver, Colorado ranks high, the chief silver-producing region of the state being Leadville. This district is situated in the Mosquito Range near the headwaters of the Arkansas river. It began its history in 1860 as a gold camp, but upon exhaustion of the gold resources the camp lost its significance as such. It then became a silver-producing camp which position it lost nearly a decade ago when Leadville became a lead and zinc camp. Eight or ten different metals are produced within the camp at the present time.

The Geology of Leadville.—The base of the mountain consists of a series of Archean granites, gneisses, schists and amphibolites. These are overlain by a series of Cambrian quartzities and shales which in turn are covered by Silurian limestones and quartzites. Above these there appear limestones, shales and grits of Carboniferous age. Associated with this vast series of sedimentaries there appears also many late Mesozoic and Tertiary irruptives (Fig. 66.)

The uplift of the Mosquito Range, of which the Leadville district forms the western slope, resulted in a series of anticlinal and

synclinal folds with many faults that have the same general direction as the axes of the fold. They do not coincide exactly with them but pass into folds at their extremities. The folds are nearly vertical on their western slope and less inclined on the east. It is along the higher and steeper slope that the greatest amount of fracturing has taken place. (Fig. 67.)

Faults: The displacement in general has been toward the east. The maximum upthrow in any one fault is recorded in the

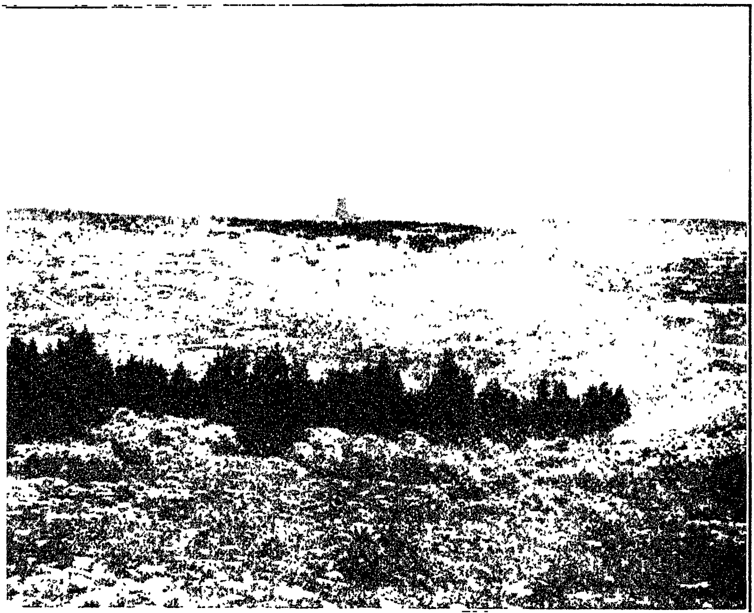


FIG. 66.—View from the top of Carbonate Hill, Leadville, Colorado, looking toward Iron Hill. The valley in center ground marks position of the Iron fault. Shaft house is that of the Tucson shaft, and ridge in distance fault scarp of Mosquito Range. (*By permission of the Macmillan Company, from Ries' Economic Geology.*)

Mosquito fault, measuring about 5000 ft. The mineral veins themselves have been folded and faulted with the enclosing sedimentary and eruptive rocks. This fact alone would prove that the mineral deposition took place prior to the dynamic movements that formed the Mosquito Range itself. (See Fig. 68.)

Mode of Occurrence: The typical form of the Leadville deposits seem to be a contact sheet whose upper surface is the Lead-

FIG. 67.—View from south end of Carbonate Hill, Leadville, Colorado, overlooking California Gulch in foreground and town of Leadville in the valley, Sawatch Range in distance. (*By permission of the Macmillan Company, from Ries' Economic Geology.*)

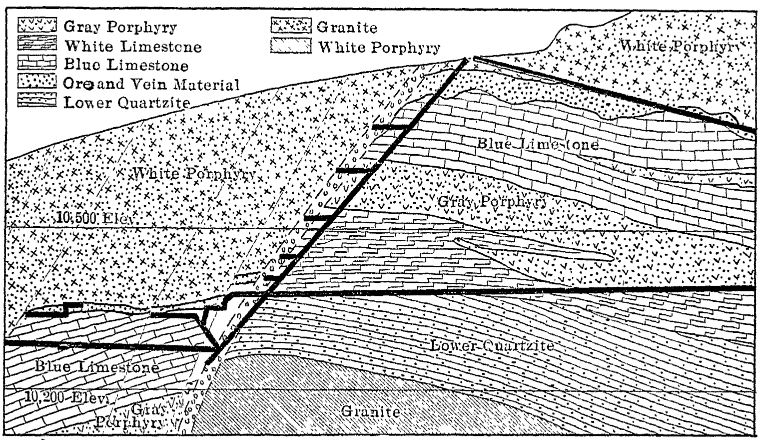


FIG. 68.—East-west section through the McKeon shaft, Leadville, Colorado, showing the faulted ore bodies along the contacts. (*After Blow.*)

ville porphyry with a regular and well-defined upper limit to the ore body. The ore occurs in the blue limestone of Carboniferous age. The lower surface of the ore body is irregular and often ill defined. It sometimes occupies the entire thickness of the limestone formation. The ore sometimes occurs near the contact of the gray porphyries with the blue limestone, sometimes in both the calcareous and siliceous beds, sometimes in the porphyries themselves either near contact surfaces or along joint and fault planes. As a rule the argentiferous lead ores occur in the blue magnesian limestone while the auriferous pyrites and the copper ores are more frequently found in the quartzites and porphyries.

Leadville Minerals: Native gold in flakes or leaflets; the silver minerals are argentiferous galenite, cerargyrite, embolite and native silver; the lead minerals are galenite, cerussite, anglesite, massicot minium, and wulfenite; the accessory minerals are sphalerite, calamine, stibnite realgar, bismuthinite, malachite, chrysocolla, wulfenite, a vanadate of lead and zinc, pyrite, and hydrous and anhydrous oxides of iron. The gangue minerals are quartz, pyrite, siderite, barite, gypsum and hydrous silicates of aluminum.

Origion of the Ores: According to S. F. Emmons, the ores were derived from a descending aqueous solution. The ores derived their metallic content from the neighboring eruptive rocks. Mr. Emmons further contends that the metals must have been formed beneath a thickness of at least 10,000 ft. of superincumbent rocks and an unknown amount of sea water; that if they had been deposited from hot ascending solutions as the result of the relief of pressure it would naturally be expected that the bulk of the deposit would have been found in the upper part of this mass of rocks where the pressure was the least, rather than at the base; that at the time of deposition the sedimentary beds were horizontal and relatively undisturbed; that if the deposits had been made from ascending currents the process of deposition would have acted from the bottom upward instead of from the upper surface downward as is shown in the case of the blue limestone which carries the bulk of the ores; that in the region of the greatest ore development there is a noticable absence of channels extending downward through which ascending solutions might have come; that the vast majority of irruptive bodies are in the form of horizontal sheets parallel with the stratification; and that the few approximately vertical bodies afford no

evidence that their walls form part of a channel through which the ore currents came up from below.

Since the work of Mr. Emmons was done at Leadville, other eminent geologists have been in the field with better opportunity to study the origin of the ore deposits. The finding of fissure ores in the Cambrian quartzite leads them to the conclusion that the ores may have been brought in by solutions ascending directly from the intrusives.

In 1859, placer gold was found in California Gulch, worked out in 1863 and deserted. The owners were much troubled with heavy rock, the composition of which was unknown to the miners, but later discovered to be cerussite, the carbonate of lead, rich in its silver content.

In 1875 these deposits were reopened and worked for their silver content. The silver occurs as argentite, native silver, cerargyrite and embolite at the surface and in galenite at greater depths. Masses of auriferous galenite have been found 100 ft. in thickness.

At Aspen, oxidized lead and silver ores occur in highly folded and faulted Carboniferous limestone. According to W. H. Weed, the accumulation of ore at the intersection of fault planes is the result of a secondary enrichment rather than of primary concentration. At Creede, the silver ores occur in fissure veins penetrating igneous rocks. At Red Mountain the silver ores occur in true fissure veins traversing Jura-Trias terranes.

Utah.—Third in order of importance as a silver producer is Utah. In both Cottonwood cañons, oxidized lead-silver ores occur near the surface in bedded veins in Carboniferous limestone. In Beaver County oxidized lead and silver ores occur in contact fissures in the Horn Silver mine; in "chamber deposits" in Carboniferous limestone at the Cave mine; in fissures at the Carbonate mine; in Park City, as silver and lead ores in Carboniferous limestone, sandstone; and shales. The ores bearing lead and copper are oxidized, the others appear mostly as bedded deposits in the limestone, often with siliceous walls separating one deposit from another. These are frequently associated with porphyritic igneous rocks. In Idaho at Coeur d' Alene the ore galenite is found with siderite gangue in highly folded quartzites and mica schist.

Nevada—The Comstock lode, Nevada, represents the largest auriferous silver-bearing deposit ever discovered. It lies in a

great fissure vein several hundred feet in width and four miles long with branching ends. The fissure follows a fault line, and at the center where the displacement is the greatest the width is 300 ft. The mine reaches a depth of nearly one mile. All the veins were originally opened for silver, for they contain silver at the surface. As the veins were worked to lower depths copper ores appeared. The silver soon became refractory and the percentage too small for profitable extraction.

The ore occurs in true fissure veins bearing native silver and the silver sulphides, associated with zinc and manganese. The gangue consists of rhodonite, rhodochrosite, and quartz. Probably there were no open fissures before the deposit occurred for the ore is deposited along fractures or cracks impregnating and partially replacing the wall rock, so that there is a gradual joining of the vein and the wall rock with no sharp line of demarcation between them.

The surface ore is black due to such manganese compounds as pyrolusite, MnO_2, resulting from the breaking down of manganese minerals. At the lower depths the mineral remains pink, the natural color of rhodonite and rhodochrosite. A conical peak 2000 ft. above the valley is cut by a pure white vein of quartz containing ruby silver in little red specks with traces of pyrite, galenite and sphalerite. This locality is remarkable for the depth of the oxidation of the ore reaching 1400 ft. on the sides and 1000 ft. in the center of the mound. This was a very important field in the production of silver before the decline in the price of the metal. The country rock is basic, diabase and diorite.

In the Eureka district, oxidized lead and silver ores, auriferous to a considerable degree, occur in a brecciated Cambrian limestone and shale.

New Mexico.—In the Lake Valley district there occur galenite, cerussite and embolite in Paleozoic limestone. At Silver City in the Breman mine, argentite and cerargyrite occur at the contact of shale and limestone impregnating both. At Lone Mountain cerargyrite, bromyrite and embolite occur in a gangue of quartz.

In Wardner County and Bitter Root Mountain, Idaho, galenite occurs in quartzite and mica schist in large chutes impregnating the fissured hanging walls. This is one of the most productive regions of the world.

In the *Thames district* the gold-silver lodes consist mainly of quartz, in which both metals are present in threads, foils and

grains. The district is cut through by two Pliocene faults, and the ores are associated with Tertiary eruptives. The ores are of hydatogenetic origin.

In the *Freiberg district* the lodes occur in metamorphic acidic intrusives. The ores are native silver, argentite and proustite. The silver ores of Japan belong to the acidic type associated with Tertiary eruptives.

Ontario, Canada.—In the Province of Ontario there are three important silver districts. In the order of their discovery they are Cobalt, South Lorrain and Gowganda. The rocks are essentially alike in the three fields. The sedimentaries consist of conglomerates, slates and schists of pre-Canbrian age. The intrusives are diabases, gabbros and granites. The silver lodes traverse the irruptives and often the veins penetrate the sedimentaries. The veins vary in width from a fraction of an inch to two feet or more. The ores are of hydrothermal origin. The silver minerals are native silver, argentite, pyrargyrite, and breithauptite, associated with smaltite, niccolite, pyrite, chalcopyrite, erythrite and annabergite. The principal gangue mineral is calcite. Quartz is sometimes present in subordinate quantity. There seems to have been a distinct order of deposition of minerals in the Cobalt district. According to Prof. Wm. Campell of Columbia University, smaltite was first introduced into fissures in the diabase, etc. This introduction was followed by niccolite and small quantities of other ores. Then there came a period of disturbance in which the vein materials were brecciated. The infiltration of calcite and the deposition of native silver in plates and threads and grains followed later. Finally bismuth ores were introduced into a few veins. The author has worked out the same order for several mines in the Gowganda district.

Geographical Distribution of the Ore.—Silver occurs in all countries. It is most abundant in Mexico, United States, Canada, Australia and Germany, arranged in order of importance. In the United States the distribution of silver is in five distinct belts: (1) The Appalachian; (2) the Lake Superior district; (3) the Cordilleran; (4) the Pacific Coast belt; and (5) Alaska. However, 90 per cent. of all the silver produced in the United States comes from Montana, Colorado, Idaho, Utah and Nevada. Therefore, the area of greatest importance is the Cordilleran section.

Geological Horizon.—Silver ores occur in the rocks of all ages. It is not restricted, therefore, to any one horizon. However, it is especially abundant in the pre-Cambrian, Cambrian, and Carboniferous rocks. It occurs in Colorado in Jura-Trias rocks. The character of the deposits may be classified as follows: (1) Most of the silver veins are true fissure veins; (2) the silver occurs as bedded deposits in limestone; and (3) as contact deposits between igneous and sedimentary rocks.

Extraction of the Metal.—There are five well-known processes used in the extraction of the white metal from its various ores; (1) Amalgamation; (2) smelting; (3) lixiviation; (4) cyanidation process; and (5) the electrolytic process.

The Amalgamation Process.—This is applicable to native silver, embolite, cerargyrite, bromyrite, iodyrite. These crushed to a powder, and ground directly with mercury without any special preparation readily form a silver amalgam. The haeloids are decomposed with a formation of silver amalgam and haloid compounds of mercury. In the case of the sulphide, argentite, metallic silver is set free and a sulphide of mercury is formed, but the process is far slower than in the case of native silver or the halogens. In the case of the arsenides and antimonides, the process is so slow that it seems advisable to roast the ore with common salt prior to amalgamation.

Some form of the amalgamation process has been known for a long time. The arrastra was introduced into America in 1557. It was used for a long period of time in Mexico. The process is simple. The ore is finely crushed, treated with water, placed in iron pans where by revolving machinery it is ground to an impalpable powder, and mixed with mercury. The revolving machinery is kept in motion four to six hours, when the mixture is complete. The amalgam is then collected and mercury distilled at a temperature of 350°, and the silver fashioned into bullion.

The "cazo" or "caldron" process is a simple method for treating surface ores containing silver, either native or in the form of chlorides or bromides. The ore is first crushed, and then finely ground in the arrastras and charged into amalgamating vessels with salt and mercury. The small receptacles originally employed consisted entirely of copper. The *fondon* took its place. This is a larger receptacle with wooden sides and copper bottom. In the fondon, two copper blocks are fastened to arms attached

to the vertical revolving shaft and dragged around on the copper bottom by motive power. It was the tendency of the amalgam in this process to adhere to the copper plates which first gave the idea of the introduction of silver plated amalgamated copper plates in the gold milling industry.

Perhaps the pan amalgamation process is the direct outcome of the cazo and fondon processes with the improved machinery as introduced by Frazer and Chalmers of Chicago. The process is continuous, and the ore is roasted before the effective amalgamation takes place, that is, amalgamation takes place far more readily and completely in the presence of roasted ore.

Smelting Process.—This refers to that method of treatment carried out largely in North America and in Germany, where the object is to obtain a solution of silver in lead. The smelting is carried on in the blast furnace of moderate size with a mixture of ore, fuel, and fluxing material. The smelting of silver ore with lead is most satisfactory under the following conditions: (1) Where there is an abundance of bituminous coal or natural gas to serve as a supply of fuel; (2) where limestone, low in magnesium, is available; and (3) where large quantities of silver-bearing galenite abound. The process is not applicable to cupriferous ores and ores free from lead or poor in silver. The process admits of a continuous discharge of lead through a siphon into some bowl or vat, while the slag is run continuously into iron kettles mounted on tracks so that the cone-shaped slags may be easily transported to the waste yards. Later the slags are run into troughs in which there flows a strong current of water. As the slag strikes the water it is immediately granulated. It is used for certain industries, as in the manufacture of cement. The lead can be ladled from the bowl, or tapped from it, or allowed to run continuously.

The Pattinson process depends upon the fact that the alloy of silver and lead can be fused easily and the silver crystallized from the lead. Silver does not form an alloy with lead to any considerable extent as the solution cools. Silver dissolves rapidly in lead at the temperature of fusion of the white metal. In the Pattinson process, when the metal is molten and allowed to cool the lead is ladled out of a large iron pot into kettles upon one side growing richer and richer in silver, and upon the other side poorer and poorer in silver. The material first to crystalize would be pure lead. The material last to solidify is the silver, and between the two, varying amounts of silver and lead are

present. This material is all remelted and recrystallized. This process is continued until only about 0.002 per cent. of silver remains in the lead.

The Rosan process is largely like the Pattinson only the liquid alloy is drawn off leaving the solidified portion. The process is less delicate or efficient than the Pattinson, giving 0.003 per cent. of silver waste in the lead.

The Parke's process depends upon the formation of compounds of zinc and silver when these metals are melted together. The alloy of zinc and silver is formed containing about 12 per cent. of silver. The zinc is added in small amounts at different times. In the first solidification practically all the gold and copper solidify with the zinc. Upon the addition of more zinc the silver unites directly with the zinc in the formation of the alloy $AgZn_{12}$. The efficiency of this method is proven by the amount of silver remaining in the lead which is about 0.005 per cent. The final step in the treatment of the alloys thus obtained is cupellation, in which process the lead is volatilized, and the gold or silver remains in the cupel.

Lixiviation Process.—The silver is dissolved, and after filtering, is precipitated from the clear liquid into metallic form by some reagent. The process is as follows:

In the treatment of argentiferous copper matter the Ziervogel process has been largely utilized, in which copper, iron and silver are present and converted into their sulphates, then into their oxides. The iron is the first to oxidize, copper second, silver third. Just as the silver begins to oxidize it is treated with water, and the silver is precipitated by scrap copper. The copper still in solution is recovered by the more electro-positive metal, scrap iron. The process is complete when the solution yields with ammonium hydroxide only a faint blue coloration, and when no dense white curdy precipitate is obtained upon the addition of common salt.

In the treatment of the ores containing copper and iron, sodium chloride was first used for the conversion of the silver into silver chloride. This process is known as the Augustine process. This, because of its general inefficiency, was supplanted by the sodium thiosulphate, otherwise known as the Patera process. This process is more efficacious, because of its greater solvent power, especially upon the arsenates, and antimonates of silver which are practically insoluble in the presence of the sodium

chloride. The sodium thiosulphate method has given way very largely to the calcium thiosulphate method, which is practically identical in apparatus and method of treatment, save with calcium in place of sodium as a solvent. The latter process is known as the Kiss process from its inventor. But all these in which calcium thiosulphate enters as a solvent are now replaced by the cyanide process.

Cyanide Process.—This method of treatment is based upon the fact that when silver sulphides, arsenides and antimonides, are treated with a solution of potassium cyanide or sodium cyanide, a double cyanide of silver and potassium, or silver and sodium is formed. The solution is far more concentrated than in the

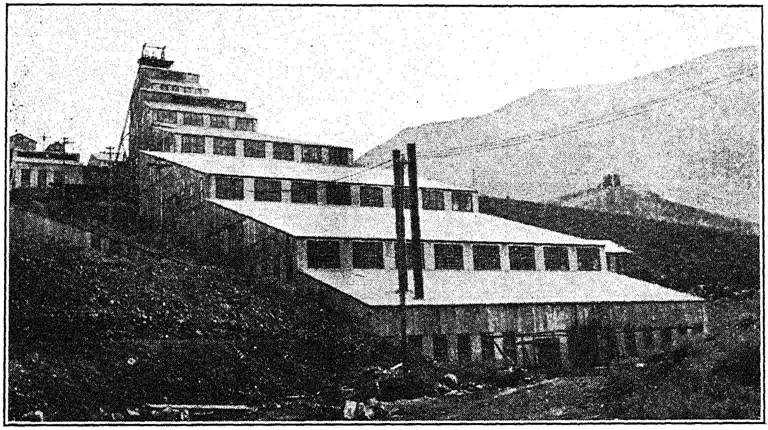


FIG. 69.—Nevada Hills mill, Fairview, Nevada, for cyaniding silver.

case of the treatment of gold-bearing ores with potassium cyanide, because the silver minerals are less soluble in a cyanide solution than the gold ores. The solution is filtered to remove all sediment, and allowed to settle to a perfectly transparent liquor. It is then drawn off into precipitating tanks, and the metal reduced to the elemental state by granulated zinc, zinc shavings, zinc dust, as in the treatment of gold. (See Fig. 69.)

Electrolytic Process.—Silver is separated from argentiferous copper ores electrolytically by sulphuric acid and copper sulphate. The copper and iron are dissolved at the anode, while gold, silver and platinum are precipitated at the cathode. In the modification of this process, known as the Moebius process, large amounts

of silver are now refined in the United States. The bath consists of a solution of nitric acid, silver nitrate and copper citrate. The silver and copper are both dissolved at the anode. The copper remains in solution, the silver is precipitated at the cathode, the gold remains undissolved.

Uses of Silver.—Silver was used by the ancients practically as early as gold. Silver is used very extensively in the arts and sciences, as in jewelry, tableware, coinage, silver bullion as a medium of exchange, photography, mirrors, for optical apparatus, in plating and in very many alloys. Copper lowers the melting-point of silver and makes the metal harder, but does not decrease the malleability, or materially impair the color. This is by far the most important of the silver alloys, and in coinage nine parts of silver to one part of copper produces a coin that resists wear through friction. Silver mixes with lead in all proportions when molten but segregates upon cooling. Therefore, silver-lead alloys lose their homogeneity. Silver alloys readily with cadmium, producing a soft, white, malleable, and ductile alloy. Silver alloys readily with mercury and produces silver amalgams. Silver unites with tin, zinc, and bismuth in the formation of important alloys, generally ductile and malleable. With platinum, silver forms a hard alloy, that is used very extensively in dentistry. Silver unites with palladium and with rhodium; in fact, silver unites with all useful metals save iron and cobalt.

PLATINUM: ITS PROPERTIES, OCCURRENCE AND USES

Properties.—Platinum, symbol Pt, is one of the rare metals. It has a specific gravity of 21.46, silver white with a grayish tinge, ductile, malleable, sectile, with a luster less brilliant than that of silver. Its melting point is 1780° C. Its atomic weight is 195. In the finely divided state it is black. The presence of minute impurities render platinum hard and brittle. In the electric crucible Moissan volatilized it, but its boiling point is unknown. It is unaffected by heat in both dry and moist air. It is insoluble in all single acids, but is readily soluble in *aqua regia.*

Ores of Platinum.—*Native platinum; sperrylite,* $PtAs_2$, which is the most important ore of the metal; *platiniridium,* an alloy of platinum and iridium; *osmiridium,* an alloy of osmium and iridium; native osmium and irridium contain small quantities

of platinum; it occurs in covellite, which is a sulphide of copper, CuS; and in laurite, which is the sulphide of ruthenium, RuS_2.

Geographical Distribution.—Platinum occurs in small quantities in the gold-bearing sands of California and Oregon. It occurs in limited quantities in Arizona, Colorado, Georgia, Idaho, and Montana. It is reported from Mexico, Santa Domingo, Brazil, and in placer deposits in Colombia. The world's principal supply of platinum comes from the Siberian side of the Ural Mountains. In Brazil at the *Congo Soco* mines it occurs in the decomposed schistose rocks associated with gold. It is also found in small quantities in the placer gravels of Alaska.

The platinum production in the United States has come from the placer mines in Butte, Humboldt, Siskiou, Trinity, Calaveras, Sacramento, and Del Norte Counties, California. Three-fourths of the amount has been obtained from Butte County alone.

The most noteworthy event of the platinum industry in recent years is the discovery of the comparatively new mineral, sperrylite, the arsenide of platinum, $PtAs_2$, which occurs in association with nickel-bearing ores of Sudbury, Ontario, and in the Rambler mines, Wyoming.

Importance is also attached to the discovery of the metal in association with several copper minerals, as covellite, the sulphide of copper, CuS. This result may lead to the discovery of platinum of commercial importance in other members of the copper group.

With the present high price of platinum, more than twice the value of gold, we may expect a persistent search for platinum ores: (1) Among the placer gravels of the serpentine rocks, especially those resulting from the metamorphism of large masses of peridotite; (2) in the members of the copper group, and (3) in the nickeliferous peridotites.

Geological Horizon.—Platinum is associated with the pre-Cambrian, Cambrian and Ordovician terranes. The origin of the ore bodies is largely through the decomposition of the superincumbent rocks, which allows platinum to be carried into the valleys where it sinks to the lower portion of the gravel and into the cracks and the crevices of the upper portion of the underlying rock. It is, therefore, intimately associated with gold in placer deposits, and may be reclaimed by the same method as gold. The common parent rock is the ultro-basic

ferro-magnesian rock known as peridotite. Many platinum placers have been traced back directly to the decomposition of such a rock. However, all peridotite does not bear platinum.

Methods of Extraction.—(1) By placer mining. Platinum is obtained by panning the lower gravels of placers or by hydraulicing and dredging the entire gravels of the larger placers for the gold. (2) The wet method. The ores of platinum are treated with hot aqua regia which dissolves all of the platinum and part of the iridium. After evaporating the excess acid the platinum is precipitated by ammonium chloride as an ammonium chloroplatinate $(NH_4)_2PtCl_6$. Ammonium chloride and chlorine are volatile upon ignition and the platinum is left behind as a spongy metal. (3) Recovery from waste solutions. The waste solution is boiled to expel any excess of nitric acid; it is then filtered to remove any platinum sponge that may have been left. Barium chloride is added to precipitate any sulphuric acid that may be present. The platinum salts now in solution are reduced to the elemental state by concentrated hydrochloric acid and zinc. Electrolysis may be substituted in place of zinc.

Uses of Platinum.—According to Pliny, platinum was known to the ancients, for it occurred in many alluvial beds associated with gold, and remained with the yellow metal after the washing of the gold. In 1735 it was recognized in Columbia, S. A. In 1740 it was exported from Jamaica to Europe. Near the middle of the eighteenth century, the Spanish government forbade its further extraction and ordered all the platinum thrown into the seas to prevent its use as an adulterant of gold. In 1819 platinum was discovered in serpentine rocks on the Siberian side of the Urals. Until 1823 the world's supply of platinum came solely from South America. Since 1824 Russia has been practically the only producer. Platinum was used by the ancients as an adulterant of gold. It is used in many forms of chemical apparatus in which a high melting-point is necessary. It is the only available metal which will withstand the continuous heat of baking, and for this reason, used extensively as pins to hold artificial teeth together. It is also used for filling teeth; platinized paper for photographic purposes; jewelry, and in coinage when alloyed with 2 per cent. of iridium, especially in Russia, where it was first introduced in 1824, on account of its malleability, its unadulterability, and its intrinsic value. Platinum is also used in the manufacture of contact points of telegraph keys; for stills or

retorts in the manufacture of crude sulphuric acid, in which case it is alloyed with 2 per cent. of iridium. On account of its infusibility and the fact that its coefficient of expansion is nearly the same as glass, platinum is used to connect outside copper wires with the carbon filament in incandescent lamps. The thickness of the filament varies from 0.01 to 0.012 in. Platinum is used in the manufacture of platinum spoons, dishes, crucibles, combs, foil and wire. Liebig, in his chemistry letters, states that without platinum it would be impossible in many cases to make an analysis of many silicates, and thus the composition of most minerals would remain unknown; without platinum the composition of our organic compounds would likewise remain unknown. Platinum is used extensively by balance makers for weights; is used in surgical and scientific instruments of precision; for the points of stylographic pens; for the balance wheels and hair springs of non-magnetic watches; for obtaining a silver color on porcelain; for platinum plating; for oxidizing silver; for the fuses of electrolytically exploded cartridges; for use with high-grade explosives like dynamite. It is used with iridium as an electrode for the electrolysis of alkaline chlorides, where an alloy of 15 per cent. of iridium can be rolled to a thickness of 0.007 of a millimeter and yet have sufficient resistivity to be used on an industrial scale. Platinum is used also in the manufacture of the platinum salts of commerce. It is also used in the making of platinized asbestos. The United States dental and electrical uses of platinum equal 50 per cent. of the world's output.

The Alloys of Platinum.—Platinum alloys readily with gold and silver, and these alloys have been discussed in the treatment of silver. Platinum alloys readily with copper in all proportions at high temperatures. The alloys are extremely hard and less liable to tarnish than the ordinary brasses and bronzes. With 81.25 per cent. copper the alloy is a golden yellow, closely resembling 18 carat gold. It is both malleable and ductile and susceptible of a high polish. Both platinum and copper alloy readily with about 4 per cent. of zinc. The alloys are extensively used in jewelry; mathematical instruments, and chronometer wheels. Platinum bronze is an alloy of platinum, nickel, and tin. With nickel, platinum forms a white, malleable, magnetic alloy. This is capable of a high polish and is permanent in moist and dry air. The presence of 3 per cent. platinum prevents steel from rusting, and is therefore of great industrial importance in the manufac-

ture of cutlery and instruments of precision. The alloys of platinum with antimony, arsenic, bismuth, cadmium and tin are generally brittle. With iridium the alloys are hard and elastic, permanent in moist and dry air, and susceptible of a high polish. This is especially true when less than 25 per cent. of iridium is present. Above that point it becomes difficult to draw the alloy into wire or to hammer it into sheets. An alloy of platinum with 10 per cent. of iridium resists the corrosive action of metals far better than pure platinum. It has been stated that up to the beginning of the present century 25 per cent. of all platinum used in the United States was iridium. We use alloys of platinum and iridium under the name of platinum. Platinum does not amalgamate readily with mercury. Here it is unlike gold and silver.

Palladium.—Palladium, symbol Pd, has the color, luster and appearance of platinum, but takes a finer polish. It is malleable and ductile, and is the most easily fused of any metals of the platinum group. It is usually found in the metallic state, sometimes with gold and silver, and also associated with platinum in the ores of the latter metal. Palladium can scarcely be distinguished from platinum by its color. It is chiefly noted for its great tendency to absorb hydrogen. It is with difficulty soluble in nitric acid. It dissolves in boiling sulphuric acid, being more easily attacked in the finely divided state. It melts at 1586° C., and at a higher temperature yields a green vapor. It forms alloys with gold, silver, copper, mercury, nickel, antimony, arsenic and the platinum metals. Palladium is used chiefly for the graduated surfaces of physical instruments and for coating silver articles, especially mirrors, because it retains a polish and does not tarnish. Its atomic weight is 106.7.

Osmium.—Osmium, symbol Os, has a specific gravity of 22.47. It is a bluish metal, harder than glass and infusible in the oxyhydrogen flame. It crystallizes in cubes or rhombohedrons and is the heaviest of all known solids. It burns in the air to the tetroxide, which has a peculiar penetrating odor and is injurious to the eye. It alloys with metals, notably iridium. It is found in the Ural Mountains, Brazil, California, Borneo and Australia. It is used in pointing gold pens and as bearings for compass needles. Its melting-point is 2500° C. Its atomic weight is 190.9.

Iridium.—Iridium has a specific gravity of 22.42 and a fusion-point of 1950° C. It is a hard, white, lustrous metal resembling steel. It is malleable at red heat. It melts only in the oxy-

drogen flame. It is brittle and very hard. It is a powerful catalytic agent when finely divided. It is obtained by igniting ammonium chloriridate, which is obtained from osmiridium or the platinum residues by a complicated process. It is found in the Ural Mountains, Brazil, California, Borneo and Australia. Its atomic weight is 193.1.

Rhodium.—Rhodium, symbol Rh, is a white, malleable, ductile metal. Its specific gravity is 12.1 and its fusion-point is 2000° C. It is insoluble in acids and unchanged in air. It is prepared from platinum residues by first converting it into rhodium chloride and then by reducing this by heating it with sulphur in a carbon crucible. It forms alloys with platinum, gold, bismuth, and lead. It is the most costly of all the metals, being worth five times as much as gold. It occurs in small quantities in platinum ores and in some native gold. It is found in the Ural Mountains and in Brazil. Its atomic weight is 102.9.

METALS OF THE PLATINUM GROUP

	At. wt.	Sp. gr.	F. melting-point	C. melting-point.
Platinum	195.0	21.5	3225	1780
Iridium	193.1	22.33	3892	1950
Osmium	190.9	22.47	4532	2500
Palladium	106.7	11.4	2732	1586
Rhodium	102.9	12.1	3272	2000
Ruthenium	101.7	12.26	3632	1950

The members of the platinum group occur intimately associated with each other. Where one is present the other members in larger or smaller quantity are usually present. Native platinum contains from 16 to 40 per cent. of the other metals of the group. These often alloy with each other as in iridosmine and platiniridium. They are all white or grayish-white, lustrous, ductile and malleable metals. They are all permanent in the ordinary atmosphere. Osmium alone burns when strongly heated. All the others are scarcely affected by oxygen at any temperature. Save palladium, they are insoluble in any single acid, and often *aqua regia* is without solvent action upon iridium and ruthenium. Palladium fuses at the temperature of wrought iron, and is, therefore, the easiest fused of any members of the group. The order of fusibility of the other metals is, palladium, platinum, ruthenium, iridium, osmium, the last of which has never suffered

fusion. All these minerals occur native and as alloys, principally as scales or granules in the placer gravels, in the same location as described under the caption of platinum. The geological horizon is the same as given for platinum.

LOSSES OF PRECIOUS METALS

The losses of precious metals may be classed as follows: (1) Hoarding. The quantity hoarded is indeterminable, and the loss is largely retrievable. (2) The amount put out of circulation as objects of art and ornamentation. (3) Wear and tear. This represents an irretrievable loss. It occurs in the wear of the coin whereby the medium of exchange to-day meeting the standard of weight, to-morrow becomes too light, as its edges and sides have become smooth. The coin is not suitable as a medium of exchange, and it goes back to the United States mint for recoinage. This loss also occurs in the gold leaf, silver leaf, wire, and in the pure metals used extensively for plating. (4) Loss in the useful metals, that is, ores containing too low a percentage of gold, or silver, or both, to separate with a profit. A small percentage of these metals goes into the useful metals as copper and iron, from which it is never removed. (5) The concentrates from milling processes from which other metals are recovered may carry so small a percentage of either gold or silver that they are thrown directly into the waste, thereby losing, for all commercial purposes, a certain quantity of silver and gold. (6) In the extraction of the metals, as reducing the ore to a pulp too rapidly, in crushing the ore too coarsely for amalgamation to take place, and in the employment of cheap labor. (7) Loss in tailings. In some plants estimation has been made that from 50 per cent. to 60 per cent. of the actual gold and silver present in the ore is lost in the tailings from the mill. If the loss in 1 gal. of water is 0.018 cent, and if 576,000 gal. of water per day represents the amount of waste, the actual loss for one year would be represented by the following:

$$576{,}000 \times 0.018 \times 360 \times 2 = \$74{,}649.60.$$

(8) By crushing the ore too finely. This produces a flour gold and silver, both of which are carried away on the surface of the water. (9) By filling the holes in the stamps and pans with amalgam. (10) By cleaning the plates too quickly. (11) By remov-

ing the amalgam from the plates too thoroughly, for the amalgamation is not complete when the plates are new or perfectly free from the amalgam, that is, "experienced" plates are far more efficient in the extraction of the gold and silver than the "inexperienced." (12) By using too slow a current of water. If the current be too slow, the plates become covered with slime, and this prevents the gold and the silver from coming directly in contact with the amalgam. (13) By using too rapid a current of water. This prevents the metal from being caught on the amalgamating plates, that is, the heavy current of water simply carries it away. (14) By not keeping the mercury clean. This prevents the amalgamation from taking place. Whenever mercury is covered with oil from the machinery, or oily exudations from the hands, it must be redistilled or treated with lye to cut the oil. (15) By the flouring of the mercury, that is, the reduction of the mercury to so fine a state of subdivision that it will not adhere to the amalgamating pans. (16) By too few amalgamating machines, as where the ore is rich and the quantity required to pass over the plates is too great for one machine to do the work. (17) By too short sluices or plates; by using the blankets too long; and by leaving the plates in front of the stamps so long that they become charged with mud and other debris and prevent the uniform feeding of the gold upon the amalgamating plates.

CHAPTER IV

USEFUL METALS (GROUP I)

LEAD AND MERCURY

Properties.—Lead, symbol Pb, is a soft, bluish-white metal. Its freshly cut surface has a bright metallic luster. The metal upon exposure quickly becomes coated with a film of the oxide. Lead, unlike the other metals, is sufficiently soft to be scratched with the thumb-nail. It even leaves a lead gray streak upon paper. Lead is fashioned into foil or wire by rolling and pressing. It is readily soluble in nitric acid but the other mineral acids are without special solvent effect upon the metal at ordinary temperatures. Its specific gravity is 11.3. Its melting-point 327° C. Its atomic weight 207.10.

Ores of Lead.—Native lead occurs in small quantities in many localities both in the United States and in foreign countries. It is always of secondary origin, the product of reduction from other lead minerals through volcanic action.

Galenite, PbS, 86.6 per cent. of lead.

Anglesite, $PbSO_4$, 68.3 per cent. of lead. A white or gray sulphate.

Cerussite, $PbCO_3$, 77.5 per cent. of lead. A white or pink carbonate.

Pyromorphite, $3Pb_3(PO_4)_2,PbCl_2$. Often in small hexagonal crystals.

Cotunnite, $PbCl_2$, 74.5 per cent. of lead.

Massicot, PbO, 92.8 per cent. of lead. A buff powder.

Minium, Pb_3O_4, 90.6 per cent. of lead. A vivid red powder.

Plattnerite, PbO_2, 86.6 per cent. of lead. An iron black oxide.

Crocoite, $PbCrO_4$, 65 per cent. of lead.

Wulfenite, $PbMoO_4$, 57 per cent. of lead.

Stolzite, $PbWO_4$, 44.9 per cent. of lead.

Galenite is by far the most important ore of lead. It crystallizes in the isometric system in perfect cubes and regular octahedrons. It also occurs massive and granular. Silver sulphide, Ag_2S,

is often intimately associated with galenite and isomorphous with it. All galenite is more or less argentiferous but the coarsely crystallized variety like the galenite of Rossie, St. Lawrence Co., N. Y., is low in its silver content, while much of the finely crystallized galenite of the Cordilleran section is highly argentiferous.

The last seven minerals are not important as ores of lead, but the artificial massicot, minium and crocoite are important in the arts and industries. Wulfenite and stolzite are interesting molybdenum and tungsten salts of the metal. There are also many compound minerals playing only a minor rôle in the metallurgy of the metal.

Origin of the Ores.—As already noted, native lead is always of secondary origin, the direct product of the reduction of other ores. The sulphide of lead is precipitated in the laboratory whenever a solution bearing H_2S comes in contact with neutral or slightly acid solutions bearing lead salts. Galenite appears to have been formed in most cases from mineralized solutions by hydro-chemical reactions, or by hydatogenetic reactions at temperatures which are not excessively high. Mayencon has reported galenite as a product of sublimation in a burning coal mine, Lacroix and Zambanini both report galenite as a Vesuvian sublimate formed during the eruption of April, 1906.

Anglesite is a common oxidation derivative of galenite in the presence of water or moist atmosphere. The carbonate, cerussite, is derived from the oxidation of other ores of lead in the presence of carbonated waters in the upper level of ore bodies. Therefore anglesite and cerussite are generally present in the oxidized zone of an ore body bearing lead minerals. The richness of the ore varies with the extent of the decomposition that has taken place. If it is limited to the breaking down of galenite the ore is sometimes very rich. If the associated country rock has also suffered decomposition the ore has absorbed so much carbon dioxide in the formation of earthy carbonates that it is often too poor in lead to pay for profitable extraction. The oxides are always of secondary origin and result directly from the decomposition and reduction of other lead minerals. The chloride of lead, cotunnite, is a volcanic mineral produced by sublimation.

Character of the Ore Bodies.—Primary galenite appears to be connected with the acid intrusives of all ages. Minerals which characterize ores of pneumatolytic origin are absent and

the galenite is hydatogenetic (Fig. 70). According to Thomas and MacAlister the Derbyshire galenite assumes a variety of forms which they have classified as rakes, pipes, flats and scrins. The

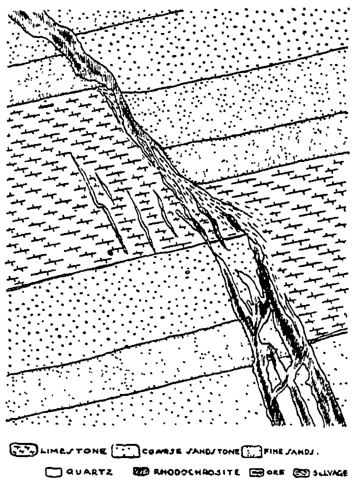


FIG. 70.—Section exposed in a breast of the Enterprise mine at Rico, Dolores County, Colorado. (*After Rickard.*)

rakes are true fissures, often faults; the scrins are mineralized fissures crossing them; the flats are mineralized bedding planes; the pipes are irregular pipe-like bodies of ore.

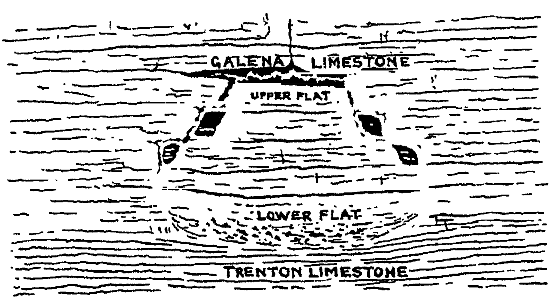


FIG. 71.—Ideal section through flats and pitches of the lead and zinc region of Wisconsin. (*After Chamberlain.*)

In the United States, lead minerals occur in veins which may be tilted to almost any angle with the strata which the fissure vein traverses. In Missouri, galenite occurs filling large cavities as

chamber deposits and as gash veins; also it occurs in what is known as flats and pitches. (See Fig. 71.)

The most important lead deposits of the United States are of

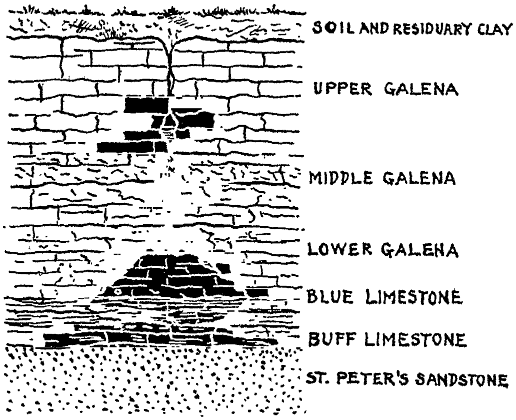


FIG. 72.—Ideal section in the lead and zinc region of Wisconsin, showing the forms of ore deposits at the different horizons. (*After Chamberlain.*)

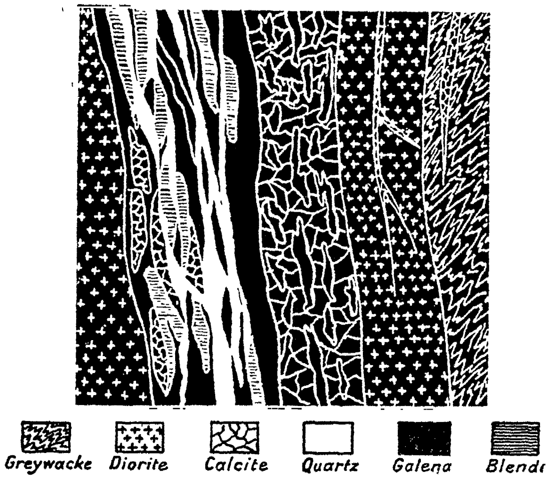


FIG. 73.—Section of the Adelbert lodes, Pribam, Bohemia. (*After J. Zadrizil.*)

metasomatic origin. They occur in the limestones of all ages (Fig. 72). Fossils have been replaced by galenite retaining both the external form and internal structure of the organism. Such

instances have been reported from Sardinia, England, and Westphalia.

The mineralizing solutions in most cases of metasomatic galenite belong to the descending ground-water currents. There are, however, examples of metasomatic replacement deposits that have resulted from the action of heated solutions rising from below in accordance with the theory of the ascensionists. Both of these deposits usually occur in limestones which interact upon percolating waters charged with solutions of lead salts. The limestones did not originally contain the galenite. Its source was some associated igneous rock or sulphide-bearing sediment. Alkaline sulphides may have aided in effecting the solution of the lead, and the lead in solution was doubtless transported as a sulphide and deposited in the place of the dissolved limestone.

Galenite is usually associated with several other minerals, common among which are calcite, dolomite, siderite, sphalerite, pyrite, rhodonite and quartz, as shown in Fig. 73.

Geographical Distribution.—Lead in its various ores is widely distributed. The mineral galenite is found in almost all countries, but few are of great importance. It occurs in the United States, England and Sweden in limestones. In the Harz Mountains it occupies veins in clay slate; in Freiberg it occurs in veins in gneiss; in Spain as veins in granite.

The United States is the largest producer of lead. The American area may be divided into three distinct fields: the Appalachian; the Missippi River belt, and the Cordilleran region.

(1) The first district is of the least importance. It extends from Alabama on the south to Maine on the north. The ores are associated with Cambrian or Cambro-Ordovician metamorphics. The belt comprises a highly folded and often faulted series of crystalline schists and limestones. In Pennsylvania galenite occurs in many places in these crystallines and is often argentiferous, varying from $2 to $2000 per ton in silver. Lancaster, Chester, Northumberland and Wayne Counties are most important sections. In New York, at Rossie, St. Lawrence Co., galenite occurs in veins 3 or 4 ft. in width. The crystals are often very large and assiciated with a calcite gangue. In Virginia the terranes associated with lead at Austin's Mines and Sterling are Cambrian and Ordovician. It is not likely that any of these localities in the Appalachain belt will ever become great producers of this useful metal (Fig. 74).

(2) The Mississippi River belt comprises the following states:—Minnesota, Missouri, Illinois, Iowa, Kansas, Kentucky, and Arkansas. The Missouri-Kansas district is the most important of them all. It is further divided into three distinct fields: (a) The southeast; (b) the central; and (c) the southwest. In the first two fields the ore is distinctively galenite. In the third district the ore is associated with zinc.

Joplin is in the southwest district. The ore occurs in limestones and chert of Mississipian age intimately associated

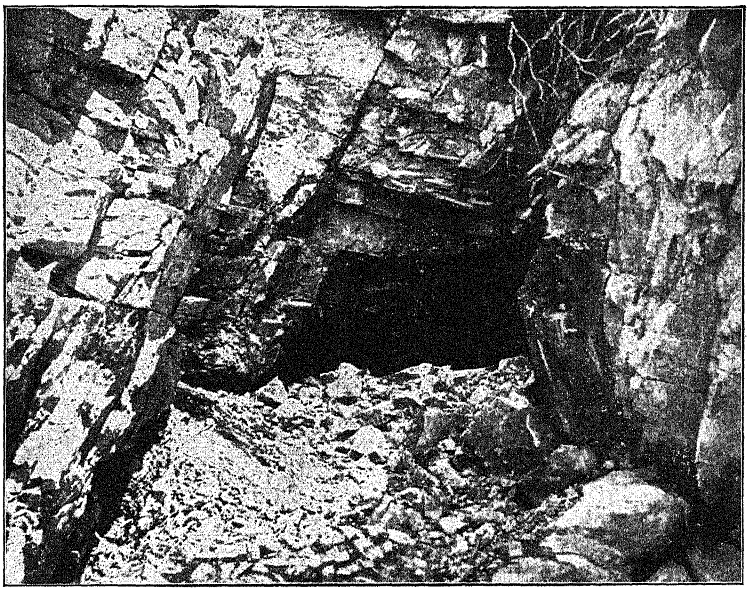


FIG. 74.—Open cut in barren ground near Iola, Marion County, Arkansas, showing jointed dolomite. (*After G. I. Adams, U. S. Geological Survey.*)

with the slates and shales of the Coal Measures. The ore bodies are often massive and sometimes hundreds of feet in diameter. The ore occurs massive and granular and in crystals of the isometric system. The associated minerals are chert, calcite, dolomite, barite and pyrite. These are all of secondary origin. The country rock is sometimes massive and sometimes fragmental (Fig. 75). In this district the ore is associated with sphalerite, ZnS, which sometimes has a resinous luster; sometimes it is the ferriferous sphalerite, containing 10 per cent. or more of

iron and known by the miners as black jack. Calamine, the hydrous silicate of zinc, and smithsonite, the carbonate of zinc, appear as associated minerals. Both of these are classified in the

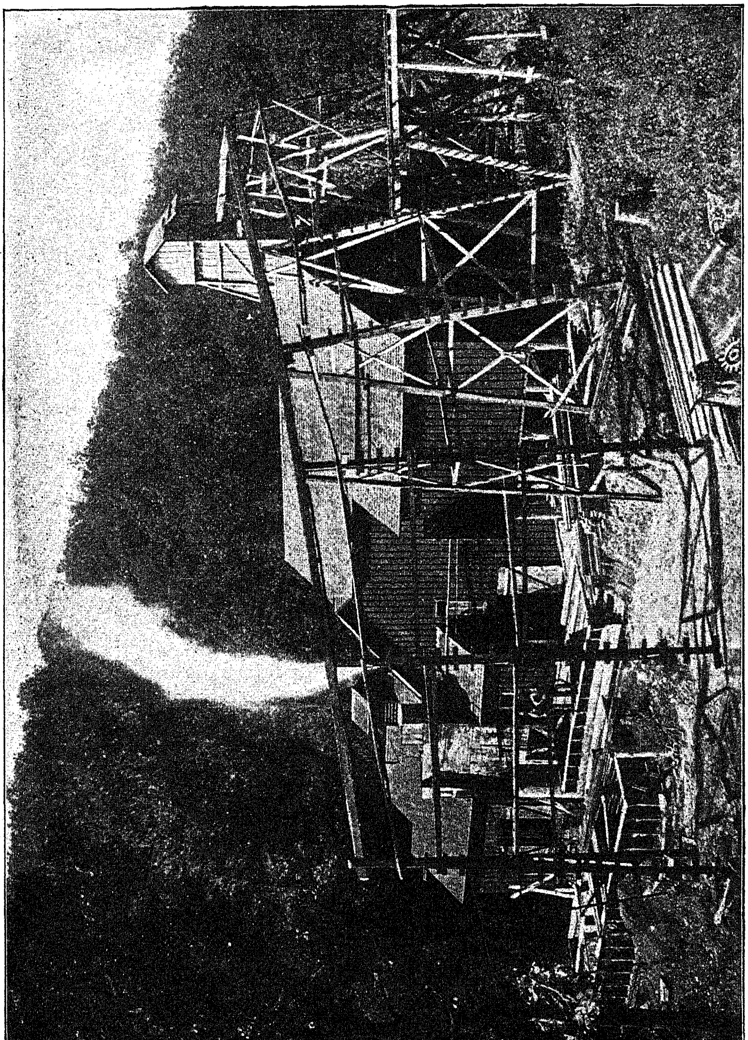


Fig. 75.—Almy mine, Boone County, Arkansas. (*After G. I. Adams, U. S. Geological Survey.*)

trade as silicates. The lenticular, tabular and cylindrical forms are more common in the southeastern and central districts than in the southwestern.

In the Doe Run mine in southeast Missouri, the ore is galenite in limestone. The ore body is sometimes from 50 to 90 ft. in diameter. It is generally in layers parallel to the stratification, but sometimes in vertical or inclined seams and occasionally disseminated through the limestone with calcite and nickeliferous pyrite, bearing pyrite or pyrrhotite as accessory minerals. The sedimentaries rest unconformably upon Archean granite and gneiss. Mine La Motte, Bonne Terre, and Doe Run are the most important mines in this district.

In southern Illinois and Kentucky the gangue mineral is fluorite, which is occasionally mined and sold to iron blast-furnace operators.

(3) The Cordilleran District: In Colorado, Leadville is the most important locality. Here the galenite is oxidized at the surface and is argentiferous. The associated rocks are Lower Carboniferous limestones and dolomites, Ordovician limestones and dolomites, and Cambrian quartzites resting on Archean granite. These terranes are all traversed by sheets and dikes of Cretaceous and post-Cretaceous age. The white and gray porphyries are older and more important. The main ore body lies in the limestone of the Lower Carboniferous age. The blue limestone at or near its contact with the Leadville porphyry is the most important horizon. According to S. F. Emmons, they constitute a contact sheet, whose upper surface, formed by the base of the porphyry sheet, is comparatively regular and well defined. The lower surface is irregular and ill defined. There is a gradual transition from ore into unaltered limestone. The ore sometimes occupies the entire thickness of the blue limestone. (See Fig. 76.)

The ore also occurs in irregularly shaped bodies or in transverse sheets not always connected with the upper or contact surface of the ore-bearing bed or rock. It also occurs sometimes at or near the contact of sheets of gray or other porphyries with the blue limestone. Less frequently it occurs in both the calcareous and siliceous sedimentaries. According to Hancock the main mass of the argentiferous galenite lies in the limestones and dolomites while the ores containing gold and copper are more pronounced in the siliceous beds, in porphyries and in the crystalline rocks.

From an economic standpoint, the most important mineral is the argentiferous galenite with its secondary cerussite and cerargyrite. Lead also occurs here as the sulphate, anglesite, as the phosphate, pyromorphite, and in the form of the oxides

massicot and minium. Native silver and embolite are both associated with the Leadville ores. The gangue minerals are quartz, siderite, pyrite and gypsum.

S. F. Emmons in Monograph XII of the United States Geological Survey Reports states:

"That the ores must have been formed beneath a thickness of at least 10,000 ft. of superincumbent rocks and an unknown amount of sea water. If they had been deposited from hot ascending solutions as the result of the relief of pressure, it would naturally be expected that the

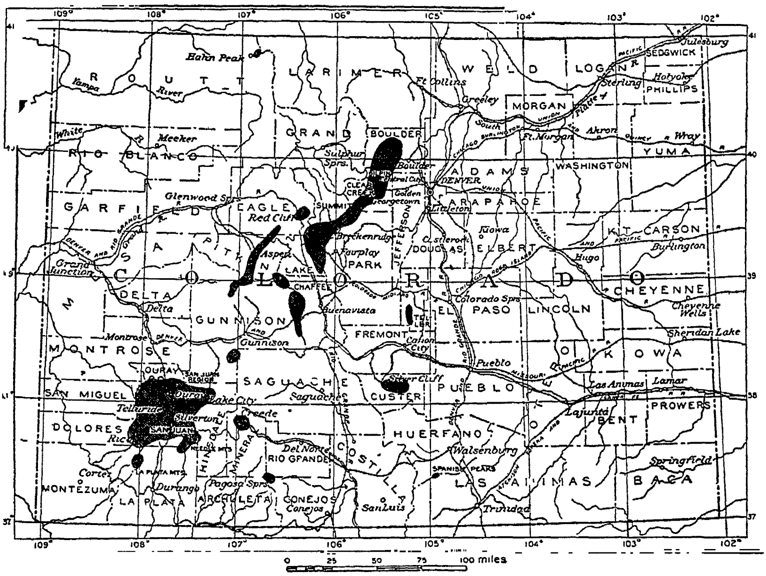


FIG. 76.—Map showing approximate distribution of the principal silver, lead and gold regions of Colorado. After Spurr. (*By permission of the Macmillan Company, from Ries' Economic Geology.*)

bulk of the deposit would have been found in the upper part of this mass of rocks where the pressure was least instead of at its base. If the deposits had been made from ascending currents it would naturally be expected that the process of deposition should have acted from the lower surface of the beds upward, instead of from the upper surface downward, as is shown in the case of the blue limestone which carries the bulk of the ores. The few approximately vertical ore bodies that have come under observation afford no evidence that their walls form part of a channel through which the ore currents came up from below. A downward current seems best to suit the facts thus far observed in the Leadville deposits."

The ore therefore seems to have been derived from the porphyries by leaching and deposited in the limestone by metasomatic replacement. The aqueous solutions traversing the joint planes and bedding planes of the limestone deposited the ore in later Cretaceous times.

Newbery and LeConte have suggested that the ores were derived from ascending solutions bearing lead salts or ores consisting of cerussite (the carbonate), galenite (the sulphide), and anglesite (the sulphate) of lead (Fig. 77).

Aspen is another important locality in Colorado in which is

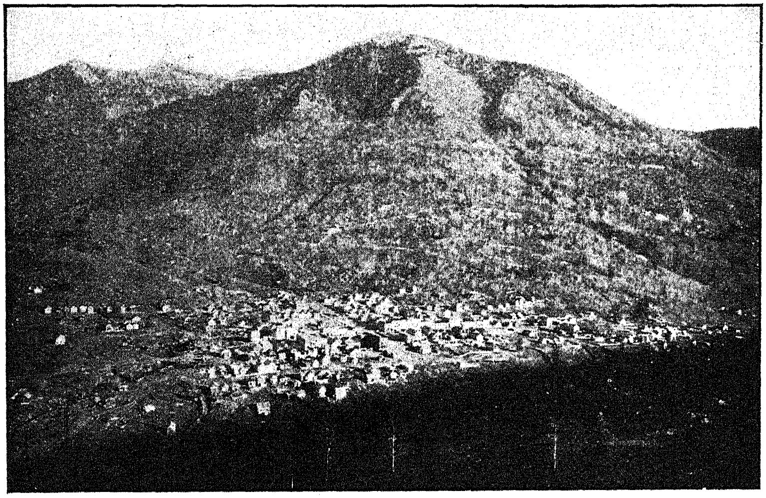


FIG. 77.—General view of Rico, Colorado, and Enterprise group of mines. (*By permission of the Macmillan Company, from Ries' Economic Geology.*)

found argentiferous lead ores. According to H. Ries, the ores are oxidized and occur in folded and faulted Carboniferous limestone, although the section involves rocks ranging from the Archean to the Mesozoic in age. Two quartz porphyries, one at the base of the Devonian and the other in the Carboniferous at present appear to bear no special relation to the ore bodies.

At the close of the Cretaceous the rocks were folded into a great anticline, with a syncline on its eastern limit. Contemporaneous with the folding there were produced two faults parallel with the bedding of the Carboniferous dolomite. At the same time much

cross faulting occurred. The ore is found chiefly at the intersection of these two sets of fault planes.

According to J. E. Spurr, the ores were deposited by magmatic waters ascending vertically along these faults and were precipitated by the reaction between the solutions and certain wall rocks, chiefly shales. The mingling of solutions at the intersection of the fissures also played an important rôle in the formation of the ore bodies.

According to W. H. Weed, the richer ore at the intersection of

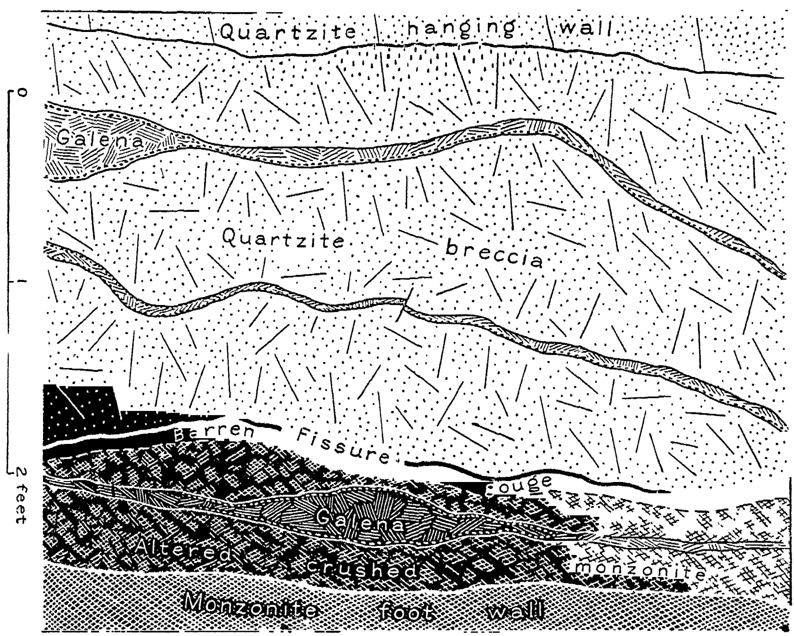


FIG. 78.—Sketch showing structure of Silver Shield lode, northeast face of stope. (*After J. M. Boutwell, U. S. Geological Survey.*)

these fault planes was due to secondary deposition, while Spurr finds little evidence of secondary sulphide formation. The ores are peculiarly free from other metals (Fig. 78).

In Utah and Nevada, argentiferous galenite yields much lead as a by-product (see chapter on the precious metals). In Idaho the bulk of the lead has been from the Coeur d'Alene district in Shoshone County. This district has for many years been one of the leading lead-producing sections of the country. The

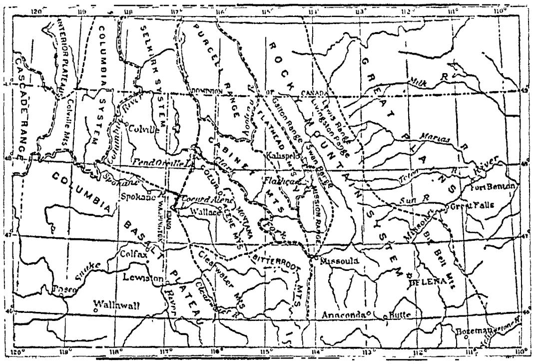


FIG. 79.—Map showing location of Coeur d' Alene, Idaho district. After Ransome. *(By permission of the Macmillan Company, from Ries' Economic Geology.)*

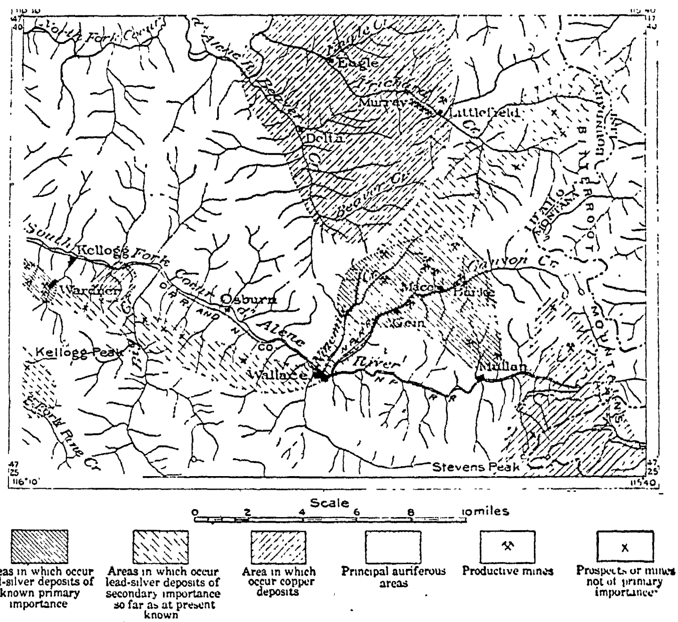


FIG. 80.—Geologic map of Coeur d' Alene, Idaho district. (After Ransome. *(By permission of the Macmillan Company, from Ries' Economic Geology.)*

Bunker Hill Mine, The Federal Mining and Smelting Company, and the Hercules Mine are some of the principle producers. Ninety-nine per cent. of the lead and the same per cent. of the silver in the Coeur d'Alene District comes from the Revette quartzite and Burke sandstones, quartzites and shales (Figs. 79 and 80).

According to F. L. Ransome, there are no sediments in the district younger than the Algonkian, except the fluviatile deposits some of which may be of Tertiary age. The post-Algonkian intrusives are monzonite and syenite. The ore deposits of the district are divided into three classes: (1) Lead-silver deposits; (2) gold deposits, and (3) copper deposits.

The lead-silver deposits occur in metasomatic fissure veins formed largely by replacement along zones of fissuring or of combined fissuring and faulting, and partly by the filling of open spaces. The ore bodies are tabular and the mineralized fissures have the characteristics of faults. They differ from the great faults of the region in that the more important faults are not ore bearing. Fissuring and cleavage are so closely related to each other that the structure may be termed a shear zone. Ries considers that the metamorphism was adequate to produce new minerals. The most characteristic minerals are galenite and siderite, the carbonate of iron. Sometimes the galenite replaces the sericitic quartzite. Sometimes the quartzite is replaced by siderite and in turn by galenite.

The galenite was not all deposited during one period for sometimes the masses of coarsely crystallized galenite is traversed by veinlets of a more compact variety of the same mineral. The lead minerals found in the oxidized zone are cerussite and pyromorphite; the silver minerals, native silver and cerargyrite; the copper minerals, azurite and malachite; and the hydrated oxide of iron, limonite.

Geological Horizon.—Lead minerals are not confined to any geological horizon. They occur widely distributed in the rocks of all ages. They are, however, most abundant in the Cambrian, Ordovician, Carboniferous, and Cretaceous ages.

Extraction of the Metal. (1) *The Reduction Process.*—Lead oxides are readily reduced to the metallic state by carbon according to the equation $PbO+C=Pb+CO$.

(2) *The Roast-reaction Process.*—The ore is crushed and introduced into a reverberatory furnace in small quantities. The ore

is first oxidized to the sulphate according to the equation $PbS+2O_2=PbSO_4$. The oxygen acting upon the lead sulphate formed in the presence of a new charge of ore reduces the sulphate to the oxide. The oxide reacts also upon a new charge of ore when some metallic lead is formed and sulphur dioxide is set free according to the equation $2PbO+PbS=Pb+SO_2$. The reduced metal sinks to the bottom of the furnace, runs through an inclined trough into an iron kettle from which the metal is dipped into moulds. The process is applicable to galenite that is fairly free from the sulphides of the heavy metals.

(3) *The Precipitation Process.*—In this process the ores may be charged in the raw state into a blast-furnace or calcined to remove volatile acid radicles or impurities. If the ore is the sulphate, anglesite, it will produce lead oxide and sulphur trioxide, thus: $PbSO_4=PbO+SO_3$. If the ore is the carbonate, cerussite, it will yield lead oxide and carbon dioxide, $PbCO_3=PbO+CO_2$. If the ore is the sulphide, galenite, it will yield lead oxide and sulphur dioxide, $PbS+3O=PbO+SO_2$ If the ore be the oxidation product, massicot, some volatile impurities may be removed. The oxide is then introduced into a blast-furnace with coke, scrap iron, or the sulphide of iron. At a high temperature the entire mass is melted. The silicate of iron rises to the surface as a slag and may be drawn off as in ordinary copper smelting. The sulphides of iron, tin, antimony, and copper, will be formed provided these metals are present and may be drawn off at a lower level. The sulphides often found are the black sulphide of copper, CuS, the sulphide of antimony, Sb_2S_3, of tin, SnS, and of iron, FeS. At the bottom of the furnace is found the metallic lead. An equation representing the reduction to the elemental state in the presence of iron would be $PbS+Fe=FeS+Pb$. The lead thus obtained is impure and is subsequently refined. If it contains silver in commercial quantities the lead is desilverized by the Pattinson process.

(4) *The Lime-roasting Process.*—This method is comparatively new and depends upon the treatment of galenite with lime or gypsum under conditions favorable for oxidation. The percentage of lead and silver saved by this method is said to be larger than that obtained by the preceding method while the cost of treatment is no greater.

Uses of Lead.—One of the most important uses of lead is in the manufacture of white lead. Lead is used also in the manufacture of other lead pigments under the name of litharge, red lead,

orange mineral and sublimed blue lead. Lead is used in the manufacture of lead pipe, shot, etc., and in many alloys that are of great commercial significance. Sheet lead is used extensively for linings to withstand the corrosive action of acids or acid vapors. In the manufacture of sulphurous and sulphuric acid the chambers and towers are lined with sheet lead. Lead is also used for the barrels utilized in the chlorination of gold and for the linings of many vats. In former years sheet lead was used for roofing and for jointing but other metals have largely taken its place. It has been used in the glazing of windows, and now an exceedingly important use is for coverings for electric cables. This use perhaps more than any other is responsible for the increasing domestic consumption.

Shot was early manufactured in Missouri and Wisconsin. Possibly this is the earliest use of lead in America. In times of peace and war a continuance of that use is very important. Lead is used also in storage batteries and in many forms of chemical works. Among the alloys type metal, britannia ware, and the various form of babbitt known as antifriction alloys are exceedingly important. It is used also in the various grades of solder as fine, medium and coarse; in the composition of organ pipes; in the fusible alloys used in electric lighting systems; in fireprotection sprinklers and in alloys with the precious metals, some of which are of commercial significance.

White lead is the most important of the lead pigments. It is used directly as a pigment and as a source of other pigments. White lead has to meet the competition of zinc white and heavy spar. These three pigments are sometimes used together. Ninety per cent. of all the white lead of commerce is manufactured by the Dutch process at New Kensington, Pa., by the Sterling White Lead Company. Their product is surpassed by none in its opacity, its covering power, and in its durability as a pigment. The process is based upon the fact that acetic acid has a strong corrosive effect upon lead. The lead is therefore immersed for several months in dilute acetic acid or vinegar, when in the presence of carbon dioxide and heat the corrosion is complete. The liquid is drawn off. The residue is placed in drying rooms which are of the filter type not used elsewhere in the world. The heat required in drying is small, only enough to remove what moisture cannot pass through the filters. Chestnut and oak bark are used in the process. The bark is exhausted only to its

most effective point. The spent tan resulting therefrom is of superior quality and its concentrated extract is sold to the leather tanneries.

Litharge is another important lead pigment. Its most important use is that of a pigment. It is used also as an ingredient in the compounding of rubber, in the manufacture of glass, in assaying, mixed with glycerine to hold pipes and table tops together. It may be manufactured from several lead salts by roasting them to drive off the volatile acid radicle. The powder obtained is a buff yellow, but if heated to the point of fusion reddish-yellow scales of the oxide appear. This product is known in the marts of trade as litharge. It is obtained in large quantities during the desilverization of lead.

Another lead pigment of considerable importance is red lead. It is not only used as a pigment but also in the manufacture of flint glass, and very extensively in the production of structural steel. It is also used as a pipe-joint cement. It can be manufactured by heating for a considerable time various salts of lead at a temperature of 450°.

Orange mineral is another lead pigment of less commercial significance. It can be manufactured by the treatment of soluble salts of lead with sodium oxychloride in the presence of an alkaline hydrate.

Sublimed blue lead is obtained as a by-product in the sublimation of galenite and consists of a mixture of lead oxide, lead sulphide, lead sulphite, zinc oxide and carbon. It is used in the manufacture of rubber goods.

Lead arsenate is used also in the destruction of the gypsy moth.

The production of lead includes base bullion, pig lead, bars, sheets and old lead. Pig lead is reported by all smelters operating in the Mississippi Valley. Refined lead embraces all of the desilverized lead produced in this country, and the pig lead recovered from the Mississippi Valley lead industry. Antimonial lead is derived from the treatment of gold and silver ores bearing antimony. In the process of extraction of the precious metals the antimony combines with the lead in the formation of antimonial lead. For this product there is quite a large demand and the two metals are never separated.

In 1885 there began in the United States the treatment of foreign ores and base bullion largely from Mexico. Part of this product is smelted and exported, but a considerable quantity is con-

sumed at home. Some lead is brought in duty free. This has considerable influence upon the annual statistics of the metal. The total valuation of metallic lead and all the pigments derived therefrom has in some years exceeded $60,000,000.

Mercury: Its Properties, Occurrence and Uses.

Properties.—Mercury, symbol Hg, is a bright, silver white, metal, liquid at ordinary temperatures. It was this physical property that gave the metal the old name of quicksilver. It is the only metal liquid at ordinary temperature. Bromine is the only other element liquid at normal temperature. At 38.8° below zero mercury crystallizes in the isometric system. The malleable and ductile cubes are of higher specific gravity than the liquid metal. The liquid metal emits vapor at ordinary temperatures. It does not tarnish upon exposure. It is not attacked by HCl, nor by concentrated H_2SO_4 without heat. It is readily soluble in HNO_3. Its specific gravity as a liquid is 13.59, as a solid it is 14.19. Its boiling point is 357°. Its atomic weight is 200.

Ores of Mercury.—*Native mercury*, Hg, is rare but sometimes reported in considerable quantity.

Cinnabar, HgS, 86.2, per cent. of mercury. The only cochineal red mineral entirely volatile before the blowpipe.

Metacinnabarite, 86.2 per cent. of mercury. The black sulphide of mercury.

Calomel, HgCl, 84.9 per cent. of mercury. Most abundant in Carniola and Spain.

Tiemannite, HgSe, 71.7 per cent. of mercury. The selenide of mercury which was once worked in the Lucky Boy claim in Utah.

Livingstonite, $HgS,2Sb_2S_3$, 24.8 per cent. of mercury. A double sulphide of mercury and antimony that has furnished a small amount of the metal in Mexico.

Amalgam, HgAg, is an alloy of silver and mercury in varying proportions. The mercury may be as low as 5 per cent. or as high as 73.6 per cent.

Origin of the Ores.—Mercury, unlike the precious and most of the useful metals is not very abundant nor widely diffused in nature. It must, however, be remembered that owing to its volatility minute traces of the metal may be easily overlooked.

Native mercury occurs in small globules scattered through cinnabar and metacinnabarite as a product of reduction by organic matter. Bituminous substances, as idrialite and napalite, are commonly associated with cinnabar. A. Liversidge reports native mercury from the hot-spring deposits of New Zealand. According to J. D. Dana, native mercury is found in Venetian Lombardy in the marl beds regarded as a part of the nummulitic beds of Eocene age. It has also been observed in the drift in Transylvania.

Cinnabar appears to have more than one method of formation. According to F. W. Clarke, mercury and sulphur, under the influence of heat, unite directly, and the product upon subliming is of scarlet hue. The black sulphide when acted upon by solutions of alkaline sulphides can be converted into the red form. The solubility of mercuric sulphide manifestly depends upon conditions of temperature, pressure, concentration, and the nature of the solution employed. G. F. Becker has found that mercuric sulphide is precipitated again from solution in alkaline sulphides upon dilution. Relief of pressure may in some cases be the equivalent of dilution as a precipitant. A. Liversidge has reported mercuric sulphide in the hot-spring deposits of New Zealand. Cinnabar has also been observed in the process of deposition by solfataric action at Sulphur Bank, California and Steamboat Springs, Nevada. The black sulphide is precipitated whenever H_2S meets neutral or slightly acid solutions of mercury salts in the mercuric state. It does not follow that the mercurial solutions have been the same in all localities. They must have varied both in their chemical composition and in the physical condition under which they came to the surface. Their properties would be modified by the differences in the rocks traversed by the solutions themselves.

Calomel is a product of secondary origin in Idria in Carniola, Almaden in Spain, Horzowitz in Bohemia, Belgrade in Servia. Amalgam is often formed where veins of mercury and silver intersect each other.

Character of the Ore Bodies.—The ore bodies bearing mercury in some cases fill fissures, fractures, or cavities in sedimentary rocks. In some instances cinnabar forms impregnation deposits in sandstones or limestones. These terranes are usually in the vicinity of igneous rocks from which the mercurial ores were originally derived. Deep-seated granites may have been the principal

source of the mercury. The ores of mercury occur in regions of crustal movement and are newer than the disturbed rocks. They are not confined to any particular formation, nor to any type of rock.

Geographical Distribution.—Mercury has a wide geographical range but its occurrence is often in so small a quantity that only a few localities have become actual producers. California has been the only large mercury producer in the United States. It occurs in many western states, New Mexico, Nevada, Oregon, Texas and Utah.

According to H. Ries, the California ores occur chiefly in metamorphosed Cretaceous or Jurassic rocks, and some even are as late as the Miocene and Quarternary. The deposits are in fissured zones. Eruptive rocks seem in many cases to be involved in the ore formation. At the New Almaden mine a rhyolite dike extends parallel with the ore body. The ore occurs along the contact between serpentine and shale, filling in part the interstices of a breccia. Branch fissures have ore-bearing channels extending into the country rock. The chief gangue minerals are quartz, calcite and dolomite. The ore is cinnabar with a little native mercury. The new Almaden mine has been one of the most important mercury deposits of the world. It has been worked to a depth of nearly 3000 ft. and the deposits are diminishing in their mercurial content. This locality is named from Almaden, Spain, where the metal has been obtained for years in great abundance.

The New Idria mine, named from Idria in Carniola, has been worked almost continuously since 1853. The ore occurs in the metamorphic shales and limestones of Lower Cretaceous age. The ore is irregularly distributed between a false hanging wall of clay and a foot wall of shale. The ore is cinnabar-bearing pyrite, with a gangue of silicified and brecciated shales and sandstones. It also occurs as impregnation deposits and in reticulated masses. Below the zone of oxidation the ore body contains tabular masses of cinnabar. Other deposits occur at Clear Lake, Sulphur Bank, and the Great Western mine. At the Great Western mine the ore occurs as chimney deposits in opalized quartz. At Steamboat Springs, Nevada, cinnabar is intimately associated with hot springs and occurs as impregnation deposits in decomposed granite. In Texas cinnabar occurs in Cretaceous limestone often faulted, in fissure veins with a gangue of calcite.

The most important deposits of mercurial ores in the world are situated in southern Spain at Almaden. The terranes consist of highly tilted and metamorphosed quartzites and shales of Devonian and Silurian age. The ore bodies occur in the quartzite as impregnation deposits, or as stringers running through the quartzite beds. The impregnations die out suddenly where the quartzites are in contact with the shales. The ore is cinnabar with some native mercury, pyrite and chalcopyrite.

Another important mine is situated at Idria in Carniola, Austria. It occurs in limestones, sandstones, shales, marls, dolomites, and conglomerates. The ore body is an impregnation deposit in the limestones and dolomitic breccias. The ore is cinnabar with a little native mercury. The gangue minerals are quartz, calcite, dolomite and fluorite. The richest deposits occupy fissures.

Geological Horizon.—The ores of mercury are not confined to the rocks of any particular age. The Almaden mine in Spain is in Silurian and Devonian terranes. The New Almaden in California is in the Cretaceous. The Peru terranes bearing mercurial ores are Jurassic.

Methods of Extraction. (1) *Distillation.*—The globules of elemental mercury as obtained from its associated gangue minerals or in pockets in the vein are contaminated with certain impurities that may be left in the retort upon distillation. The metal distills at a temperature of 350° as free from other metals. In this process the metal must be kept free from oil or oily surfaces for these "deaden" the mercury. This process is utilized in the recovery of mercury from the amalgams of gold and silver obtained in the reduction of the precious metals.

(2) *Roasting.*—The ores of mercury are crushed and roasted in large furnaces of from 40 to 50 tons capacity per day until the last traces of the metal are driven off. The temperature used is a bright red heat. This high temperature is needed in order to warm the furnace air and the new feeds of ore. In this process the sulphur is oxidized to sulphur dioxide, which when conducted into water forms sulphurous acid used so largely in the manufacture of paper by the sulphite process.

(3) *Sublimation.*—As calomel volatilizes without suffering decomposition it is only necessary to crush the rock bearing this secondary mineral and drive off the chloride of mercury as a

vapor by heat. The calomel condenses in the cooling chambers as a white sublimate.

Uses of Mercury.—The most important use of mercury is to form amalgams. Most metals amalgamate with mercury. Sodium and potassium amalgams are used in organic analysis. Tin amalgams are used in ordinary mirrors, gold and silver amalgams in filling teeth. A common amalgam for this purpose consists of silver, copper and tin with enough mercury to amalgamate the mixture. Copper and zinc likewise amalgamate with mercury. The largest single use lies in the extraction of the precious metals from their various ores. Mercury is used in thermometers but these are not accurate at temperatures exceeding 30° below zero. Mercury is used also in the arts, as in the electrolytic process for the manufacture of sodium and chlorine. The metal is unattacked by a large number of gases, therefore it is used in collecting and measuring gases which are soluble in water. Mercury compounds are used in medicine of which calomel is the most important. The bichloride of mercury, known as corrosive sublimate, is used in mercurial ointment and as an antiseptic for dog bites and snake stings. The sulphide is used as a pigment under the name of vermilion.

The unit of measure for mercury is different from that of the other useful metals. The liquid metal is put up in flasks. Each flask contains 75 lb. The value of the metal is determined by the market at San Francisco. An average quotation is about $45 per flask. The output of mercury in the United States in 1910 was 1,612,500 lb.

There are two conditions that oppose a large production of the metal. One is that many of the cinnabar deposits are situated far from transportation and fuel. The other is that small capital is not likely to be attracted to such localities.

CHAPTER V

USEFUL METALS CONTINUED (GROUP II, SUBGROUP A)

BISMUTH, COPPER AND CADMIUM

Bismuth: Its Properties, Occurrence and Uses

Properties of Bismuth.—Bismuth, symbol Bi, is a silvery white metal with a reddish tinge. Unlike the other metals, save antimony, it is extremely brittle. It is unoxidized at the ordinary temperature in dry air while it is slowly oxidized in moist atmosphere. The reddish tinge on the exposed surfaces of the metal is the result of such oxidation. It expands 2 per cent. upon cooling and this property is responsible for its extensive use in the manufacture of safety plugs for boilers. Chemically it is closely allied to arsenic and antimony. It is soluble in HCl; specific gravity, 9.8, melting point, 269° atomic weight, 208, and crystallizes in the hexagonal system.

Ores of Bismuth.—*Native bismuth*, Bi, 100 per cent. It is often associated with gold, silver, and several of the useful metals.

Bismuthinite, Bi_2S_3, 81.2 per cent. bismuth.

Guanajuatite, Bi_2Se_3, 63.7 per cent. bismuth.

Tetradymite, Bi_2Te_3, 51.9 per cent. bismuth when sulphur free.

Bismutite, Bi_2O_3,H_2CO_3, 80.6 per cent. bismuth. A basic carbonate of doubtful composition.

Bismutosphaerite, $Bi_2O_3,Bi_2(CO_3)_3$.

Bismite, Bi_2O_3, 96.6 per cent. bismuth.

There are also arsenates of bismuth, a tellurate, a vanadate, a silicate and an oxychloride of the same base, but these are rare minerals. The native metal and the sulphide, bismuthinite, are the most widely distributed of the bismuth minerals and therefore the most important ores.

Origin of the Ores.—Native bismuth results from the reduction of other ores of the metal. The important deposits of bismuth in Bolivia may be primary. The bismuth is intergrown with

cassiterite, and wolframite may sometimes be present. The sulphide of bismuth is sparingly soluble in the alkaline sulphides and in that way may be transported some distance from the original ore body. The artificial sulphide is precipitated in the chemical laboratory whenever hydrogen sulphide comes in contact with a neutral or slightly acid solution of the metal. According to F. W. Clarke, the precipitated sulphide of bismuth heated with an alkaline sulphide at a temperature of 200° has given crystals of bismuthinite. The carbonates of bismuth are of secondary origin. The action of carbonated waters upon other bismuth minerals has produced bismutite. In Australia bismutite has been observed as an ocherous deposit around a thermal spring. Bismite is also secondary in origin, the oxidation product of bismuthinite. According to Mayençon, bismuthinite occurs as a product of sublimation from burning coal mines.

Character of the Ore Bodies.—There appears to be no well-marked group of bismuth veins. The bismuth ores are best regarded as subordinate constituents of other mineral-bearing veins, yet occurring occasionally in such commercial quantities as to establish exceptional modifications of those veins. Veins of bismuth minerals occur in gneiss and other crystalline rocks, also in clay slate, accompanying various ores of silver, cobalt, lead and zinc. In Queensland auriferous bismuth ores are connected with granite intrusives. In New South Wales auriferous bismuth veins occur near the contact of granite and slate. In Bolivia the tin-bismuth veins appear to be connected with dikes of dacite and trachyte traversing altered clay slates.

Geographical Distribution.—The best known locality for bismuth minerals in the United States is in Colorado. Lake County is the best producer of the brittle metal. According to H. Ries, some of the gold ores on Breece Hill near Leadville contain from 5 to 8 per cent. of bismuth. In the same state near Golden at Bismuth Queen Lode bismuth ores are encountered. It is found also at Beaver City, Utah, and near Tucson, Arizona. In fact, the Cordilleran section bears many scattered occurrences of bismuth ores. Bolivia, Germany and Austria are the large producers of the metal.

Geological Horizon.—The ores of bismuth do not appear to be confined to any geological horizon, but are more abundant in the older geological formations.

Methods of Extraction.—Bismuth is obtained in large quantities as a by-product in the treatment of gold, silver and lead ores. Two methods that are applicable to the treatment of bismuth ores may be outlined as follows:

(1) *Roasting.*—The ore is crushed, and then heated in retorts. The molten metal drains off through inclined iron pipes. The crude metal thus collected is dissolved in nitric acid, forming the nitrate of bismuth, $Bi(NO_3)_3$. This product is treated with water and the subnitrate of bismuth is formed according to the equation,

$$Bi(NO_3)_3+2H_2O=BiO,\ NO_3,H_2O,+2HNO_3.$$

After the precipitate has thoroughly settled the supernatant liquor is drawn off, the precipitate dried, and the oxide, Bi_2O_3, is formed. This oxide when roasted in large crucibles yields elemental bismuth and carbon monoxide according to the equation, $Bi_2O_3+3C=2Bi+3CO$.

(2) *Chlorination.*—The bismuth ore is crushed, pulverized, and placed in a series of wooden vats and leached with chlorine solutions. The disengaged chlorine dissolves the bismuth. The resulting solution is clarified by filtering. It is then conducted into water when the bismuth oxychloride, BiOCl, is formed. The bismuth oxychloride thus precipitated may be dried and sold directly or it may be roasted with lime when chloride of lime and elemental bismuth are obtained. There are several other processes for the manufacture of metallic bismuth in foreign countries but owing to the minor importance of the metal they are omitted.

Uses of Bismuth.—Bismuth is used in the treatment of the precious metals for, like lead, it acts as a collecting agent for these metals. Its recovery power is very high for both gold and silver. The most important use of bismuth is in the manufacture of many alloys which are capable of wide industrial application. Perhaps the most important of these is Wood's fusible metal which melts at 65°. The alloy consists of 4 parts of bismuth, 2 parts of lead, 1 part of tin and 1 part of cadmium. The melting-point is far lower than that of any of its constituents. Bismuth melts at 269°, lead at 327°, tin at 232°, and cadmium at 321.7° C. Other alloys are Lippowitz' metal, fusing at 60°; Dorocot's metal, fusing at 93°; Newton's fusible metal, fusing at

94.5°; Rose's metal, fusing at about 100°. The range of the melting point of these alloys between 60° and 100° renders them capable of industrial application, as on passenger and freight trains where gas is used for lighting and as safety fuses for electrical apparatus. Britannia metal is an alloy which carries 1.8 per cent. of bismuth. One variety of type metal carries 7.6, per cent. of bismuth. With zinc the alloys of bismuth are always of definite composition.

The alloys of bismuth expand upon cooling, therefore they make fine, hard, sharp castings and are used for safety plugs to fill blow holes in boilers. These alloys are used also in the production of wood cuts. Some of the alloys known as bismuth solders have so low a melting point that they can be used directly under hot water. Bismuth is used also in the manufacture of clique metals. It is utilized in the preparation of glass of high refractive power. Bismuth unites with mercury in the formation of dental amalgams. Bismuth is used quite extensively in medicine, the subnitrate being the most important compound. It is used in cosmetics, in calico printing and several of its salts in the chemical trade. Bismuth is one of the most objectionable constituents in brass.

The world's supply of bismuth has long been controlled by Johnson, Mathey & Co. of England, who have regulated absolutely the production of bismuth, the price of the metal, and the supply of its ores. An attempt has been made to establish a price that would be renumerative to both the mine owners and the producers. The price of bismuth ores in London depends upon the bismuth content. With the metal at $1.25 per pound the following values would be attached to the ores: 10 per cent. ore would be worth $150 per ton; 15 per cent., $200; 20 per cent., $350; 30 per cent., $550; 35 per cent., $650; 40 per cent., $750; 45 per cent., $850; 50 per cent., $1000.

The small amount of bismuth ore produced in the United States was formerly sent abroad for reduction. Plants have recently been established at St. Louis, Missouri and Grasselli, Indiana, for the recovery of bismuth from lead ores. Bismuth, as already noted, is contained in other ores than lead, but most of the bismuth passes into the atmosphere through the smelter flues unrecovered. It is estimated that 880 lb. of bismuth are thrown off in every 24 hours in the smoke and gases of the Washoe smelter.

Copper: Its Properties, Occurence and Uses

Properties of Copper.—Copper, symbol Cu, is a copper red to reddish-brown, soft, ductile and malleable metal. Its color as copper red is best seen by reflected light. It is extremely tough, therefore, capable of being drawn out into exceedingly fine wires or hammered out into thin leaves. Its ductility and malleability are greatly diminished by the presence of impurities. As an electrical conductor it is second only to silver. The metal slowly tarnishes in dry air but in a moist atmosphere it is readily coated with a basic green carbonate. It is readily soluble in the mineral acids. Its specific gravity is 8.9. It melting point is 1065. Its atomic weight 63.57.

Ores of Copper.—*Native copper,* Cu, 100 per cent. copper but often alloyed with gold, silver, lead and mercury.

Chalcocite, Cu_2S, 79.8 per cent. copper. A gray sulphide.

Covellite, CuS, 66.4 per cent. copper. An indigo blue sulphide.

Bornite, Cu_2S,CuS,FeS, 55.5 per cent. copper. Known as horseflesh ore by miners.

Chalcopyrite, $CuFeS_3$, 34.5 per cent. copper. The most important source of the metal.

Tetrahedrite, $4Cu_2S,Sb_2S_3$, 30.4 per cent. copper. Often argentiferous.

Tennantite, $4Cu_2S,As_2S_3$, 57.5 per cent. copper.

Enargite, $3Cu_2S,As_2S_5$, 48.3 per cent. copper.

Chalcanthite, $CuSo_4,5H_2O$, 25.4 per cent. copper. A natural blue vitriol.

Brochantite, $CuSO_4,(3CuOH)_2$, 62.4 per cent. copper.

Cuprite, Cu_2O, 88.8 per cent. copper. The red oxide of copper.

Tenorite, CuO, 79.8 per cent. copper. The black oxide of copper.

Malachite, $CuCO_2,Cu(OH)_2$, 57.4 per cent. copper. The green carbonate.

Azurite, $2CuCO_3,Cu(OH)_2$, 55 per cent. copper. The blue carbonate.

Nantokite, Cu_2Cl_2, 64.1 per cent. copper.

Atacamite, $CuCl_2,Cu(OH)_2$, 59.4 per cent. copper.

Dioptase, $CuSiO_3,H_2O$.

Chrysocolla, $CuSiO_3,2H_2O$.

Origin of the Ores.—Copper is widely distributed in nature. The metal is easily oxidizable and also easily reduced. It there-

fore occurs both as native copper and in its numerous compounds. Copper is found in small quantities in the igneous rocks and therefore in the sedimentaries derived from them. It is a common constituent of sea water, and the green color of the sea has been attributed to its presence. Copper has been obtained in the ashes of sea weeds and found in certain varieties of corals.

According to F. W. Clarke, native copper is commonly, if not always, of secondary origin, either deposited from solution or formed by the reduction of some solid compound. Pseudomorphs of copper after cuprite are well known. W. S. Yeats has described pseudomorphs of copper after azurite from Grant County, New Mexico. W. Lindgren states that the vein of metallic copper at Clifton, Arizona, appear to have been derived from Chalcocite. T. Carnely has shown that native copper is soluble in saline water. Small quantities of native copper have been found at both the Ely mine in Vershire, Vermont, and in the Corinth mine in Cornith, Vermont, that appear to have been formed from very dilute sulphate solutions. The greatest known deposits of metallic copper are found in the Lake Superior region. F. W. Clarke states its original home was, perhaps as sulphide, in the unaltered igneous rocks, but its concentrates are now found in the sandstones, conglomerates, and amygdaloids. In the sandstones and conglomerates it acts as a cement. It also replaces pebbles and even boulders a foot or more in diameter. A. C. Lane has cited a corroded quartz crystal which was mainly replaced by copper. Frequently native copper has been reported as holding enclosed nodules of native silver. According to F. W. Clarke, if these metals had been deposited from a fused magma they should not have solidified separately, but as an alloy.

R. Beck mentions native copper filling the marrow cavities of fossil bones in the Peruvian sandstones of Corocoro, Bolivia. E. Haworth cites films of copper in the shales near Enid, Oklahoma, which were precipitated by organic substances.

The largest single mass of native copper ever found was discovered in the Minnesota mine, Michigan, in February, 1857. It was 45 ft. long, 22 ft. wide and 8 ft. thick. It weighed 420 tons. It was 90 per cent. pure copper and contained an appreciable amount of silver. The value of that single specimen at the average price of copper would be about $83,000.

Chalcopyrite is the most important ore of copper. Bornite and chalcocite are next in importance at least among the sulphides.

These three minerals have been repeatedly indentified as of magmatic differentiation. They are doubtless the primary compounds from which the other ores in most cases were derived. B. Lotti has reported chalcopyrite, bornite and chalcocite in Tuscany as original segregations in serpentinized rocks. J. F. Kemp has reported primary bornite in a pegmatite vein near Princeton, British Columbia. The various sulphides of copper are often of hydatogenetic origin. Sulphides of more electropositive metals may have served as precipitating reagents. Cupric solutions formed in the upper part of copper-bearing ore bodies reacting upon pyrite precipitate chalcocite. Covellite may be precipitated from copper sulphate solutions by the reaction of chalcocite. Chalcocite may alter into chalcopyrite and bornite.

According to Thomas and MacAlister chalcopyrite may be of metasomatic origin. The mode of deposition of chalcopyrite in a certain number of deposits like those formed in limestone or at its contact with other rocks leads to this conclusion. The same authors state that the solutions may have come from above or below. The solutions were transported in the form of sulphates, either due to the oxidation of pyrite in the neighboring rocks, or in the form of aqueous emanations from an igneous magma during the later stages of its cooling. They also state that the metasomatic chalcopyrite deposits are due to ascending or descending solutions of sulphides carrying hydrogen sulphide and alkaline sulphides.

The sulphates of copper are formed by the oxidation of the surface ores of copper and iron and the concentration of the mine waters. At Wicklow, Ireland, and Rio Tinto, Spain, chalcanthite thus formed has been a workable deposit. According to H. Ochmichen, chalcanthite occurs in Chili as an impregnation deposit in partially decomposed granite rocks with the hydrous carbonates and silicates as associated minerals. Brochantite is far more common than is usually supposed and can be easily formed by natural reaction.

The two basic carbonates of copper, malachite and azurite, are common copper ores of secondary origin. They are formed in the upper portion of ore bodies by the action of carbonated waters upon copper compounds or by the reactions between cuprous solutions and limestone. At Corinth, Vermont, the author has found fine specimens of both malachite and azurite formed from chalcopyrite by the action of carbonated waters.

L. Michel has reproduced azurite by leaving a solution of copper nitrate in contact with a crystal of calcite for several years. The carbonates have also been observed in the patina of ancient bronzes.

Nantokite, the cuprous chloride, is rather rare, but atacamite, especially in Chili, is important. According to J. D. Dana, it may be formed by the oxidation of nantokite. F. W. Clarke states, that it has been observed upon ancient coins and bronzes. The fumes of HCl acting upon tenorite has produced a hydrous chloride that is not far from atacamite in composition and corresponds very closely to the hydrous chloride found at Mount Vesuvius as a product of volcanic emanation during the eruption of 1872.

The two oxides, cuprite and tenorite, are always of secondary origin. They may be formed by the oxidation and reduction of other copper minerals. Cuprite is far the more important species. It has been observed as an incrustation upon ancient objects of copper or bronze.

Of the two silicates of copper, dioptase and chrysocolla, the first is rare but the second becomes an important copper ore in certain localities. According to F. W. Clarke, chrysocolla is formed by the action of silica-bearing waters upon soluble compounds of copper. Also that the mineral may possibly be produced during the processes of secondary enrichment.

H. Ries gives the following classification of the origin of copper ores:

(1) Magmatic segregations. No workable deposits of magmatic origin are known in the United States.

(2) Contact deposits in crystalline limestone along contact with igneous rocks. The copper has been introduced by vapors from the igneous rocks.

(3) Deposits formed by ascending circulating hot solutions, depositing ores in fissures, pores, spaces of brecciation, and by replacement of rock.

(4) Lens-shaped deposits in crystalline schists representing a concentration of material from a disseminated condition in the surrounding rocks.

The last two are by far the most important, but even here the ores have been enriched by oxidation and the transference of soluble compounds of copper to lower levels to be reprecipitated by limestone and the sulphides of copper and iron.

Character of the Ore Bodies.—Primary copper sulphides are found at Cornwall, England, in veins containing cassiterite. In Norway, where primary sulphides occur, tin is absent and the ores are associated with greisen and derived from acid irruptives during their solidification. In Telemarken in Southern Norway copper ores occur with tourmaline in granites, gneisses and schistose rocks. At the Ely mine in Vershire, Vermont, the chalcopyrite is associated also with tourmaline. The ore occurs

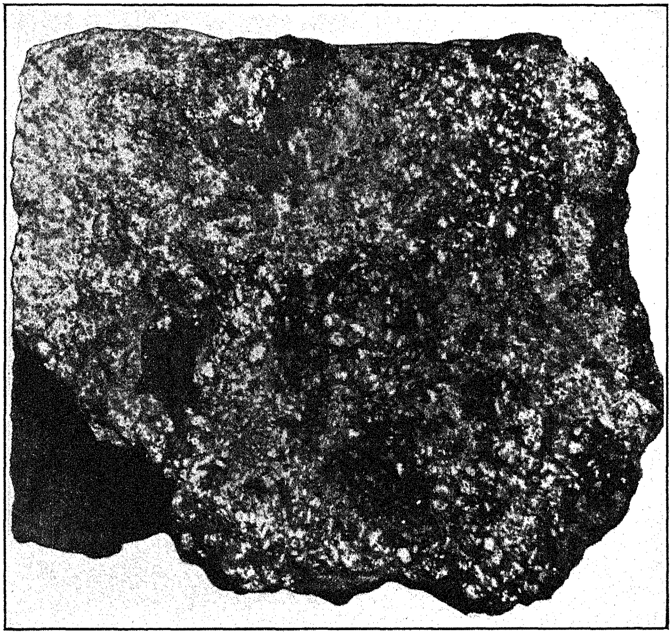


FIG. 81.—Polished specimen of copper ore from Rambler mine, Wyoming. The dark mineral in corellite. The light is kaolinized feldspar. (*After Mineral Resources*, 1902, *U. S. Geological Survey.*)

in saddle-shaped bodies along the folds in the Vershire schists or in long chimneys at the contact of the intrusive granite with the Vershire schists. Pyrite and pyrrhotite are the common associated sulphides. The granite was the parent home of the copper and the chalcopyrite was deposited under pneumatolytic conditions. This mine was known and worked before copper was discovered in the Lake Superior region. In the earlier days with 16 per cent. copper ore the mine was capable of pro-

ducing 10,000,000 lb. of copper per annum, but in the later years much of the ore has not exceeded 3 per cent. copper.

According to Thomas and MacAlister, sulphidic copper ores occur in South Australia in veins sometimes 30 ft. in width and of hydatogenetic origin. They occur in the mica schists of Cambrian age and the associated minerals are pyrite, hematite and molybdenite. They also describe in New South Wales the existence of interbedded veins of a cupriferous pyrrhotite with chalcopyrite, chalcocite and magnetite present.

Metasomatic replacements of copper ores occur at Bisbee, Arizona, and in the Lake Superior region. The high grade copper ores of northern Italy are considered by some to be of the same origin (Fig. 81).

The form then that the various copper deposits assume are veins, contact zones, impregnations and replacements in sedimentary rocks.

Geographical Distribution.—The copper ores of the United States form five distinct belts: (1) The Appalachian belt; (2) the Lake Superior region; (3) the Cordilleran section; (4) the Pacific Coast belt, and (5) the Alaskan belt.

(1) *The Appalachian Belt.*—This belt extends from Alabama on the south in a northeasterly direction to Newfoundland on the north. The richest deposits occur in Tennessee, Vermont and Newfoundland. The largest producing mine in the belt is at Ducktown, Tennessee. The ore occurs as true fissure veins in the crystalline schists. It consists chiefly of chalcopyrite in pyrrhotite and pyrite with a little quartz and is the richest where the pyrrhotite is the most abundant. According to H. Ries this district was one of the earliest producers of copper in the United States. The operations were commenced as early as 1850. The ores resulting from secondary enrichment were soon worked out and it was not until 1890 that the underlying low-grade sulphides were successfully worked. Since that time the mine has been a steady producer.

At Gold Hill, North Carolina, chalcopyrite occurs in true fissure veins found along sheeted planes in the metamorphics. Pyrite is associated with the copper ore.

At Virgilina, Virginia, the ore is bornite with a little chalcopyrite and pyrite. It occurs in true fissure veins filled with quartz and sulphides. The veins conform to the banding of the mica schists. Replacements of the wall rock are rare. In Green

County, Virginia, segregations of native copper, together with the oxides, cuprite and tenorite, and the carbonates, malachite and azurite, occur along sheared zones in the altered rocks of Algonkian age.

In Pennsylvania, New Jersey and Connecticut, deposits of native copper are found along the contact of diabase and the intruded sandstones. The mines in these states have never been large producers (Fig. 82).

The four copper mines worked from time to time in Vermont are the Ely mine in Vershire; the Corinth mine in Corinth; the Elizabeth mine and the Strafford mine in Strafford, Vermont. These are all in Orange County, and are now idle owing in part

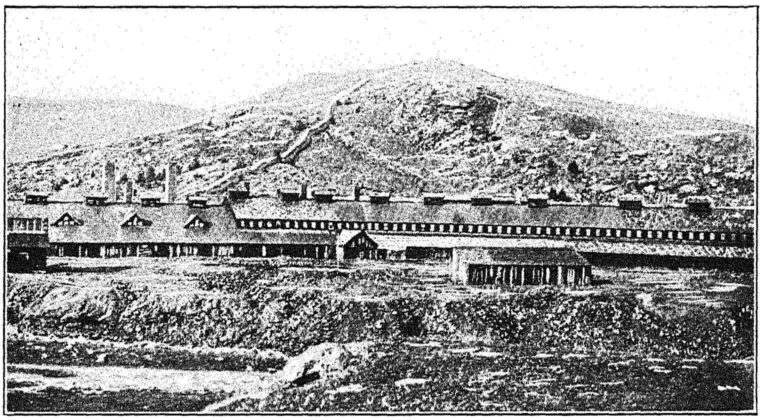


FIG. 82.—Ely mine, Copperfield, Vermont, showing the large slag beds in the foreground. (*By courtesy of the Vermonter.*)

to the depletion of the available ore bodies and in part to the distance from railroad. The chief ore in each was chalcopyrite associated with pyrrhotite and pyrite. The ore is in saddle-shaped bodies in the Vershire schists and in chimneys at the contact of the granite with the Vershire schists. The schists and the associated limestones are of Ordovician age. Tourmalines and garnets are abundant (Fig. 83).

The copper ores of the Appalachian belt are somewhat auriferous. The early attempts to work the ores for both the gold and the copper content resulted in failure. The Vermont ores averaged about $2 per ton in gold. The Newfoundland ores are higher in their gold content. Much of that ore assays from $2

to $6 in gold. Some of the veins on the eastern coast of Newfoundland are true fissure veins traversing sandstones and conglomerates. Intrusive diabase appears to be the home of the copper ore. Chalcopyrite and pyrite are the chief minerals.

Chalcopyrite occurs in considerable quantity at Capleton, Province of Quebec, in a sheared amygdaloid. The mine has been a steady producer for a number of years.

(2) *The Lake Superior Region.*—This region was discovered by Douglas Houghton in 1830. It has since that time produced more native copper than all other localities put together. In fact it has become one of the most famous copper producing districts of the world. The rocks, known as the Keweenaw series, consist

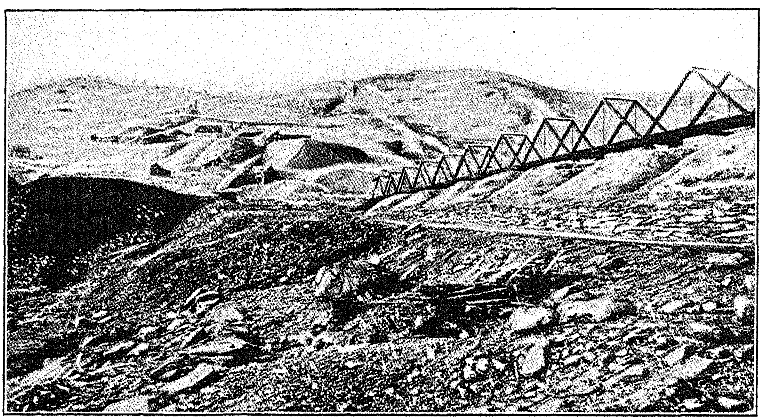


FIG. 83.—Dump piles of the Ely mine, Copperfield, Vermont. (*By courtesy of the Vermonter.*)

of interbedded lava flows, sandstones and conglomerates. The conglomerates consist of rounded fragments of a reddish quartz porphyry of igneous origin.

The ore is native copper occasionally associated with native silver. It occurs, according to H. Ries: (1) As a cement in the conglomerate, or replacing the conglomerate; (2) as a filling in the amygdules of the lava beds; and (3) as masses of irregular and often large size in veins with calcite and zeolitic gangue. (See Fig. 84.)

According to A C. Lane, the original lava flows was the home of small percentages of copper, and while these basaltic rocks were still heated they absorbed sea waters charged with sodium

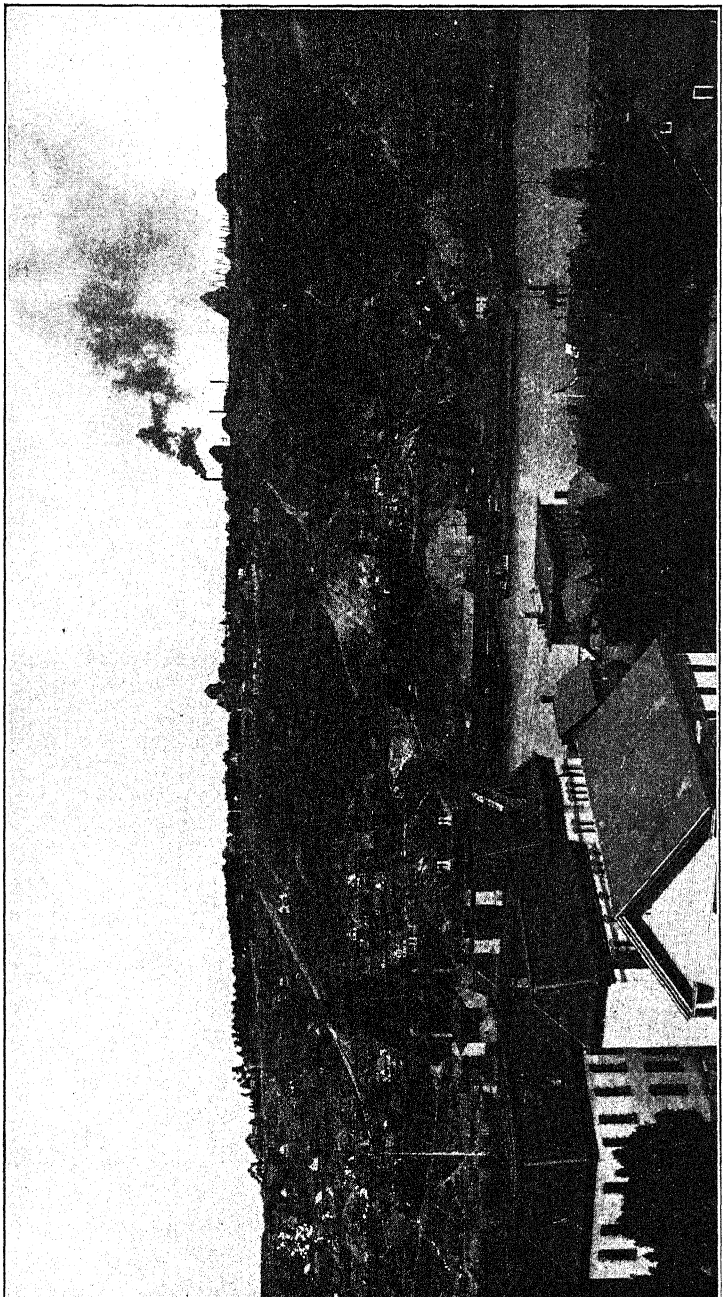


FIG. 84.—View from Houghton, Michigan, looking north toward Hancock, and showing a portion of the ridge under which the copper deposits lie. (*By permission of the Macmillan Company, from Ries' Economic Geology.*)

chloride. Meteoric waters transferred the sodium chloride downward and in their downward transition they dissolved the copper as copper chloride. Reactions between the original minerals of the volcanics and the copper solution gave rise to native copper, calcium chloride and soduim silicates.

The following assemblage of facts bearing on the source of the copper in the Lake Superior district is taken directly from the masterly work of A. C. Lane on the Keweenaw Series of Michigan.

(A) The dissemination of copper in small quantities throughout the formation. The average from several thousand feet of drilling at the Clark-Montreal mine was 0.02 per cent. Hardly a single amygdaloid fails to carry less than 0.02 per cent. copper, and when the copper content reaches 0.5 per cent. it is nearly an ore.

(B) The occurrence of native copper in similar formations of the red rock associated with salt waters and lavas elsewhere, notably in the New Jersey Triassic, in the Bolivian Puca sandstone, in Nova Scotia, around Oberstin, in the Naho melaphye region, and in Alaska.

(C) The general absence of native copper outside the Keweenawan, in the Lake Superior region, but—

(D) Native copper has been found in iron ore (generally thought to be formed by the action of downward working waters) in a few places.

(E) The water in the formation is of three kinds.

(*a*) At and near the surface soft and fresh with sodium in quantities more than sufficient to combine with the chlorine.

(*b*) At some distance (generally 500 to 2000 ft., before it attracts attention, unless especially sought) the chlorine is higher and the water is charged with common salt. The line between the two classes of waters is often quite sharp.

(*c*) At greater depths a strong solution of calcium chloride contains some copper.

(F) The middle water *b* often contains more salt than it could possibly have were it a mixture of *a* and *c*.

(G) The lines between the different kinds of waters are not regular, yet the lowest water probably always comes within 2000 or 3000 ft. of the surface.

(H) The amygdaloids seem, other things being equal, to contain rather stronger (more saline) water than the conglomerates.

(I) An unequally heated solution corresponding to mine water

c will precipitate copper on the same minerals, prehnite, datolite, etc., on which it occurs in the mine, as Fernekes has shown.

(J) The traps contain combustible gases, as R. T. Chamberlain has shown.

(K) Certain beds are abnormally rich in copper for many miles.

(L) Copper often replaces chlorite, and in the Calumet & Hecla, pebbles chlorite replaces felsite, and the copper the chlorite.

(M) Copper may even replace vein quartz.

(N) Copper is formed generally after those minerals which are the products of alteration and contain lime, and before those secondary minerals which are the products of alteration and contain soda and potash.

(O) Therefore at the time the copper formed the mine water might have lost lime but could not have lost sodium. The rock might have lost both.

(P) The Calumet & Hecla lode averages less rich (very rich in spots) near the surface, attains its greatest richness at a certain depth, say about 2,000 ft., and then gradually decreases in richness.

(Q) The silver occurs more abundantly in the upper levels.

In producing the copper solution and guiding it in its circulation Lane considers the following factors:

(A) The waters were originally contained in the lava.

(B) That which early filled it, whether it was buried on land or beneath seas, may have included condensed volcanic vapors containing copper chloride, as in Stromboli, or in the evaporation of desert pools.

(C) The absorption of water in the hydration of the rocks.

(D) The absorption of water in the cooling of the formation (water in cooling shrinks more than rock).

(E) Faults in the formation facilitating the intermingling of solutions of different compositions.

(F) Erosion of the formation and concentration of the copper contained either in pools on the land surface or in the water which found its way down into the rocks, while the deposition of the Keweenawan as a land formation was going on.

(G) The ordinary circulation of the water entering at the higher parts and emerging in springs.

(3) *The Cordilleran Section.*—(See Fig. 85.) Butte, Montana, is the most important mining camp in this district. In fact it is

one of the largest producers of copper in the world. Its output has been approximately 2,000,000,000 lb. of copper. It has further-

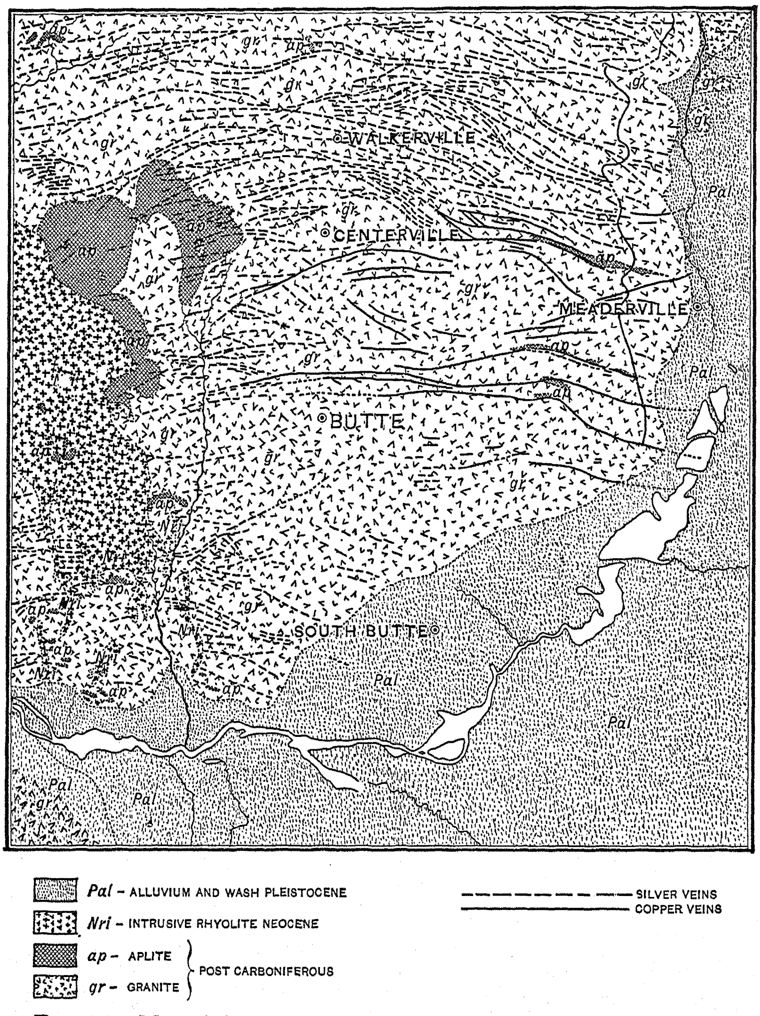


FIG. 85.—Map of the eastern part of Butte, Montana, district, showing distribution of Veins and geology. (*By permission of the Macmillan Company, from Ries' Economic Geology.*)

more produced more than 100,000,000 oz. of silver and 500,000 of gold. The camp began its mining career as a gold producer in 1864. It held this recognition until 1875 when it became a

silver camp. It maintained this position until about 1880 when it became a copper camp. It will always remain in the literature of mining geology as distinctively a copper camp (Fig 86).

The primary ore was chalcopyrite and pyrite. It is the enormous deposits of secondary chalcocite that have been the large producers of the metal. Other copper minerals appearing as ores are bornite, enargite, covellite and tetrahedrite. The veins are

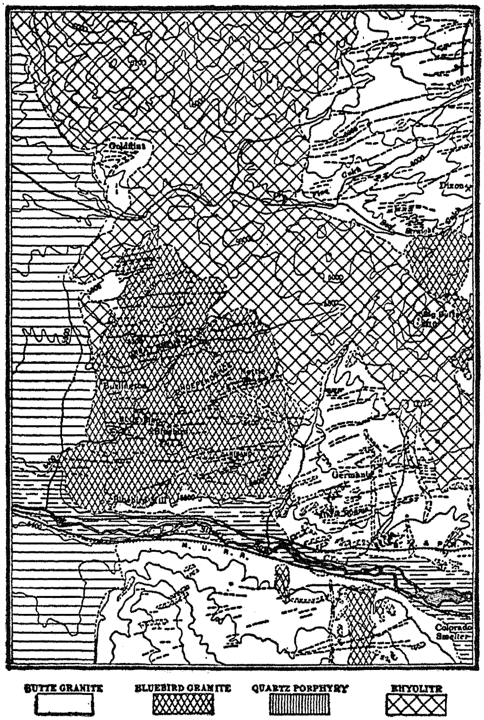


FIG. 86.—Geologic map of the western half of Butte, Montana, district. (*By permission of the Macmillan Company, from Ries' Economic Geology.*)

quite largely replacement deposits along fissures in the sheeted granite. The country rock consists of two types of granite. One is a dark hornblendic granite or quartz monzonite known as the Butte granite. The other is an acid granite or better an aplite termed the Bluebird granite. These granites are intersected by dikes of quartz porphyry. Dikes of both intrusive and extrusive rhyolite intersect the copper veins.

According to H. Ries, the veins exhibit a curious uniformity of direction, most of them striking nearly east and west, and few of them departing more than 15 or 20 degrees from the vertical.

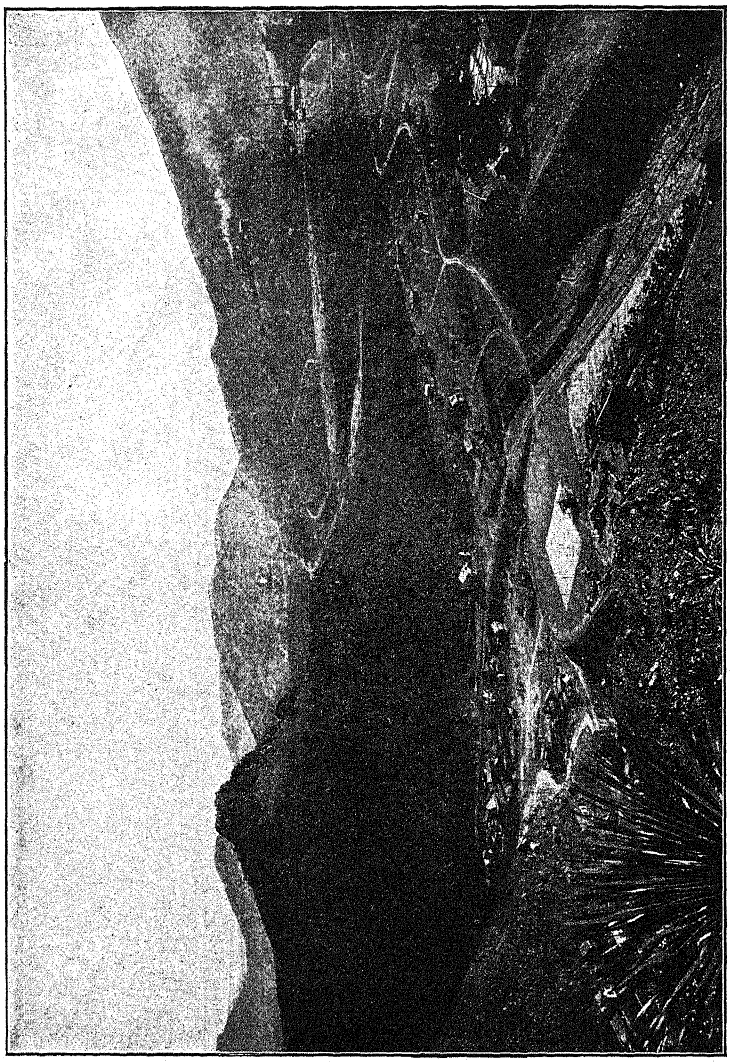


FIG. 87.—Sacramento Hill from the north, showing the various mines in the limestone around the intrusive mass of porphyry. (*After F. L. Ransome, U. S. Geological Survey.*)

They show considerable variation in width, ranging from a few feet to 150 ft. where the altered country rock is impregnated with chalcocite. In some instances there is no distinct hanging wall

and the distinction between the vein and the country rock becomes commercial.

The surface material consists of a red or brown quartz. Beneath

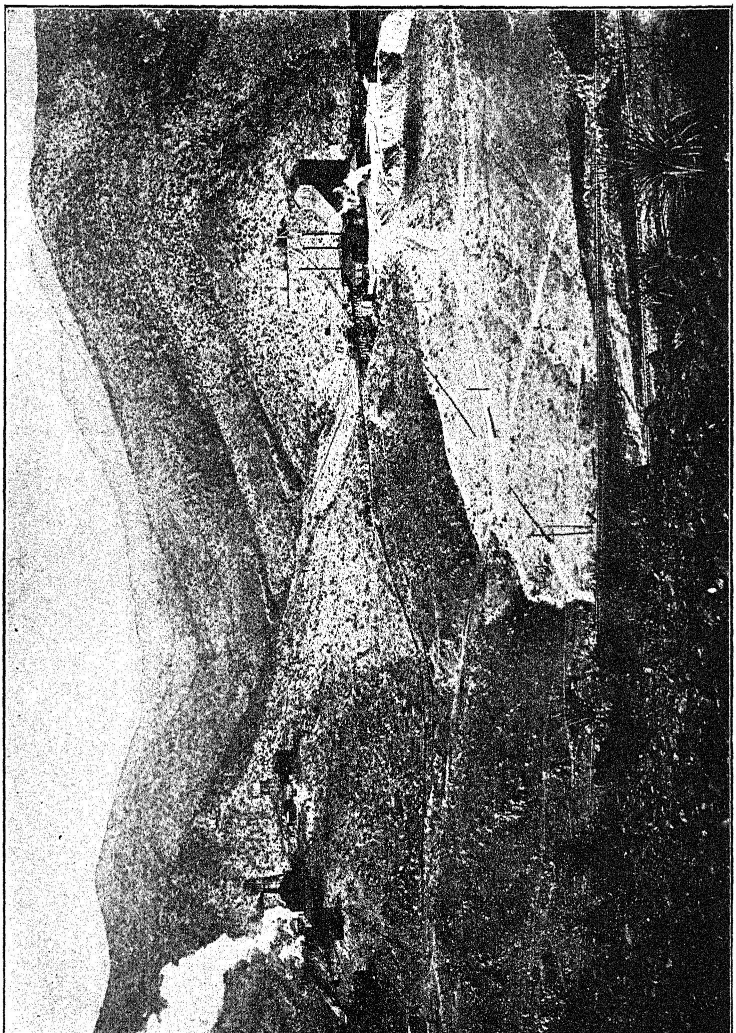


FIG. 88.—Irish May and Spray shafts from Sacramento Hill, Biskee, Arizona, Zu Spray shaft is on the right. (*After F. L. Ransome, U. S. Geologica Survey.*)

this there is a zone of oxides carrying both gold and silver. The alteration products at times reach a depth of 300 ft. or more, depending upon the susceptibility of the original material to the

agencies of the weather and meteoric water. Beneath this there is a zone of unaltered sulphides which furnish the main ores of the camp.

According to W. H. Weed, hot alkaline solutions leached the metals from the granite at considerable depths and wherever the fissures were open they were filled with ore and where the fissures

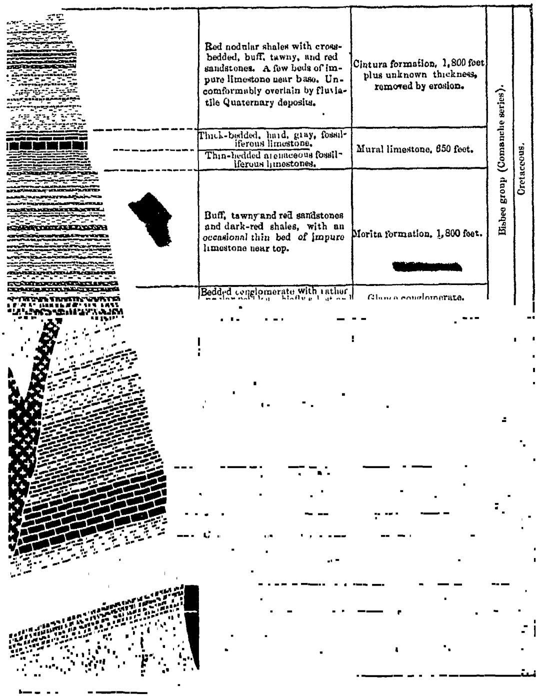


FIG. 89.—Geological section at Bisbee, Arizona. After Ransome. (*By permission of the Macmillan Company, from Ries' Economic Geology.*)

were narrow their walls were replaced, so that the vein matter shades off into the country rock.

Arizona.—In Arizona, the southern division of the Cordilleran region, there are five important copper districts. The Bisbee; Clifton-Morenci; Globe; Jerome, and Mineral Creek. (See Figs. 87 and 88.)

(1) The Bisbee district is situated on the eastern slope of the Mule Mountains and is only a short distance north of the international boundary with Mexico. The ores are found in

faulted strata, ranging from pre-Cambrian to Cretaceous. Often the fault plane forms a boundary for the ore body. The intrusions of a granitic magma have metamorphosed Carboniferous limestones and produced characteristic contact minerals. The ore-bearing solutions have risen from unknown depths and the ores occur as replacement deposits in the limestones. The sur-

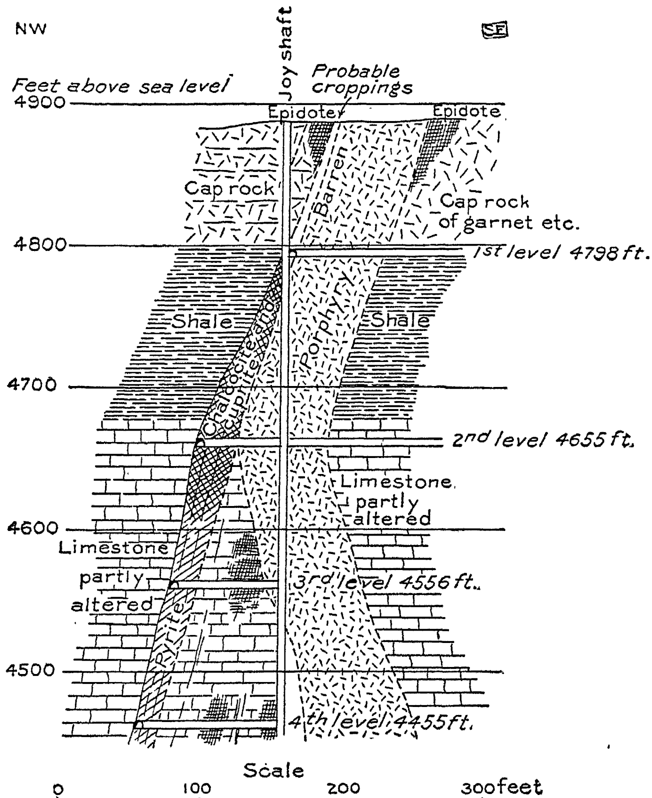


Fig. 90.—Vertical cross section of the Joy Vein, Clifton Morenci district, Arizona. (*After W. Lindgren, U. S. Geological Survey.*)

face ores were originally sulphides of copper, lead and zinc. These remain unaltered at the lower depths but in the upper portions of the ore bodies the oxygenated ores of copper, cuprite, malachite and azurite appear. (See Fig. 89.)

(2) The Clifton-Morenci District: This district from a geological standpoint embraces many conditions closely related to

those at Bisbee. Mineralogically the conditions differ more widely. The geological section embraces igneous and sedimentary rocks ranging in age from pre-Cambrian to Quarternary. Post-Cretaceous granitic and dioritic porphyries cut all the older formations. The ores are dependent upon the porphyries for their existence. The ores occur in the porphyry, or close to its contact, or along dikes of the porphry as it cuts the sedimentaries. These fissure veins traversing the granite, porphyry, and clastic rocks carry, in their unoxidized portions, chalcopyrite, pyrite and sphalerite, while in the oxidized portion the leaching out of the copper and its down-

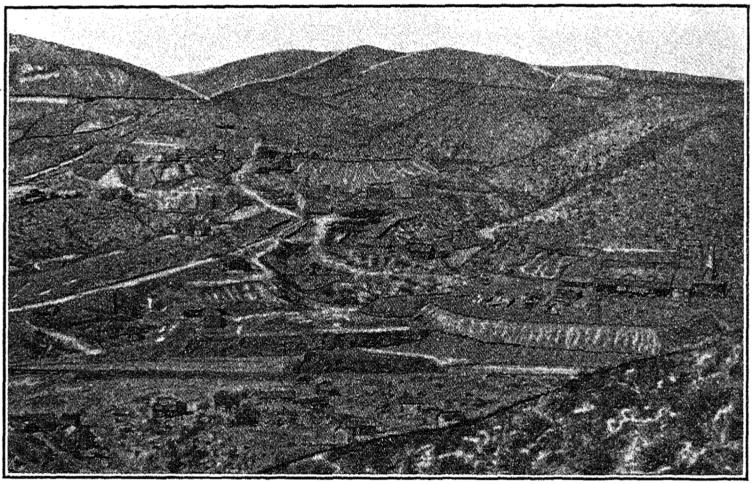


Fig. 91.—The Old Dominion mine and smelter from the west, Globe, Arizona. (*After F. L. Ransome, U. S. Geological Survey.*)

ward transference has given rise to secondary chalcocite. (See Fig. 90.)

(3) The Globe District: According to H. Ries, the ore bodies occur as lenticular replacements in limestones and fault lodes, or fissure zones in diabase. The ores in the upper levels are of the oxidized type. At the lower levels they are enriched. Some bodies of primary ore with commercial significance have been developed. (See Fig 91.)

(4) The Jerome District: The rocks of this district are pre-Cambrian metamorphics. The ores are of the same age and replace a schist that has been formed by the intense shearing of the basic porphyry. The ores are bornite and chalcopyrite with a

little sphalerite. The percentage of chalcopyrite is higher in the alternating bands of sulphide copper ores and schist than it is in the more massive material (Fig 92).

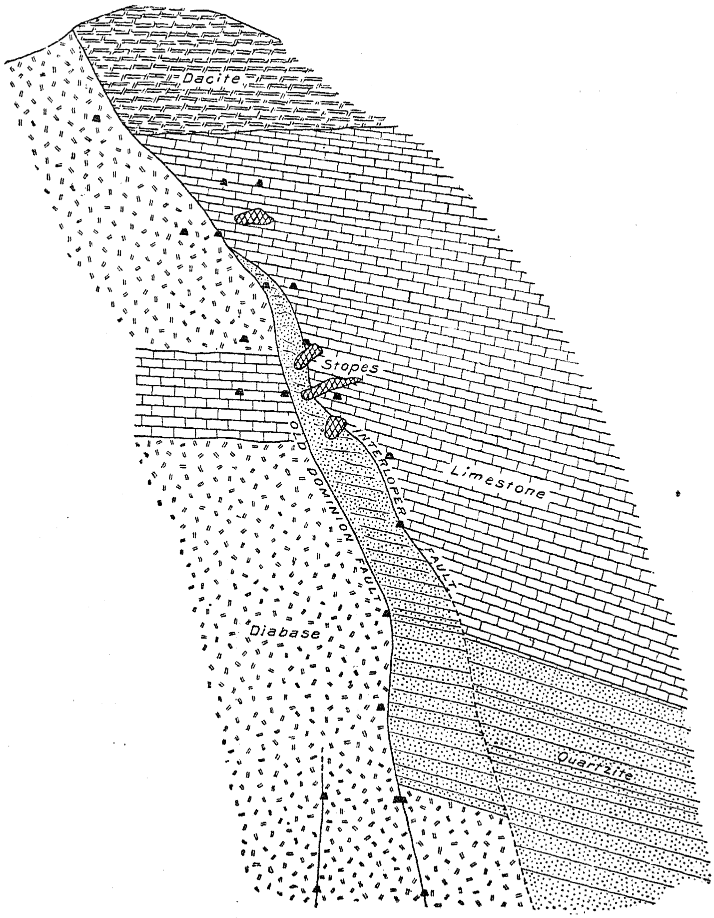


Fig. 92.—Diagrammatic cross section through the Old Dominion mine showing the occurrence of a mass of limestone in the diabase of the foot wall, Globe district, Arizona. Scale 1 in. =200 ft. approximately. (*After F. L. Ransome, U. S. Geological Survey.*)

(5) The Mineral Creek District: The terranes are pre-Cambrian and the ore is chalcocite widely disseminated through the schistose rocks.

(4) *The Pacific Coast Belt.*—California is the largest producer

of copper in this western belt. The most important field is near the northern end of the Sacremento Valley in Shasta County. The ore occurs in Permo-Carboniferous and Triassic lavas and tuffs. The ores are of the sulphide type and the lodes vary from a few inches to hundreds of feet in width.

Chalcopyrite, chalcocite and bornite occur in the Iron Mountain district as impregnation deposits in a zone of crushed breccias in rhyolite. Chalcopyrite, pyrite, quartz and barite occur in the Bully Hill district in a sheared zone following a dike of

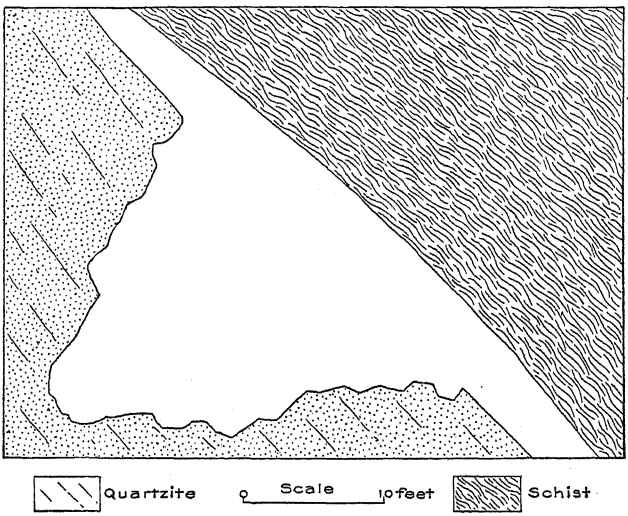


FIG. 93.—Ferris-Haggerty mine, Bonauza stope, Encampment district, Wyoming, showing form of the ore body. (*After A. C. Spencer, U. S. Geological Survey.*)

diabase. The ore lies either in the dike or at the contact with rhyolite. Chalcopyrite and pyrite occur in lens-shaped masses in the metamorphic slates and schists in the foothills of the Sierra Madre Mountains.

The Bingham Disrtict, Utah: According to E. T. Hancock, this field includes an oblong area of about 24 square miles. It lies between the Jordon Valley on the east and the Oquirrh range of mountains on the west. The terranes are Carboniferous quartzites and limestones that have suffered extensive intrusion, intense fissuring, and partial burial beneath an andesite flow. The ore

bodies are centered in the localities which have undergone the most extensive intrusion and fissuring.

The copper ore occurs in flat lenses in the metamorphosed limestones. In the Highland Boy mine there are large lenticular bodies of chalcopyrite in the fissured marble adjacent to the intrusives. The ore occurs disseminated through the igneous rocks, and limestone.

According to J. M. Boutwell, heated, aqueous, mineral-bearing solutions, rich in carbon dioxide and potassium oxide, rose along strong northeast and southeast fracture zones, altered their walls by adding quartz to quartzite, impregnating marble with metallic sulphides and specular iron ore, and silicifying, seriticizing, and impregnating monzonite with metallic sulphides and depositing lode ores in largest volume between calcareous and carbonaceous walls, mainly by filling, and partially by replacement. The same author furthermore states that "it is probable that the principal scource of the copper ore in the limestone was the magma of the intrusive, that the mineral elements were transported by the intrusives and by the thermal solutions and vapors emitted from both their superficial and deeper portions and that the ore was deposited by molecular replacement of a metamorphosed, at least partially marmorized and silicified, country rock" (Figs. 93 and 94).

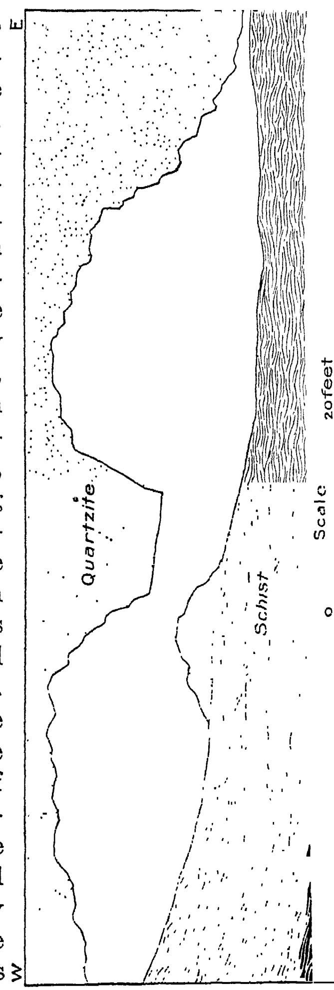


FIG. 94.—Ferris-Haggerty mine, Bonanza stope, Encampment district, Wyoming, showing form of ore body. (*After A. C. Spencer, U. S. Geological Survey.*)

(5) *The Alaskan District.*—In Alaska there are four distinct

copper fields or districts. The Prince of Wales Island; Prince William Sound; Copper River district, and the Kotsina district. (See Fig. 95.)

(1) On Prince of Wales Island, contact metamorphic ores occur in irregular masses along the contacts of the intrusives with limestones. The copper mineral is chalcopyrite. It is associ-

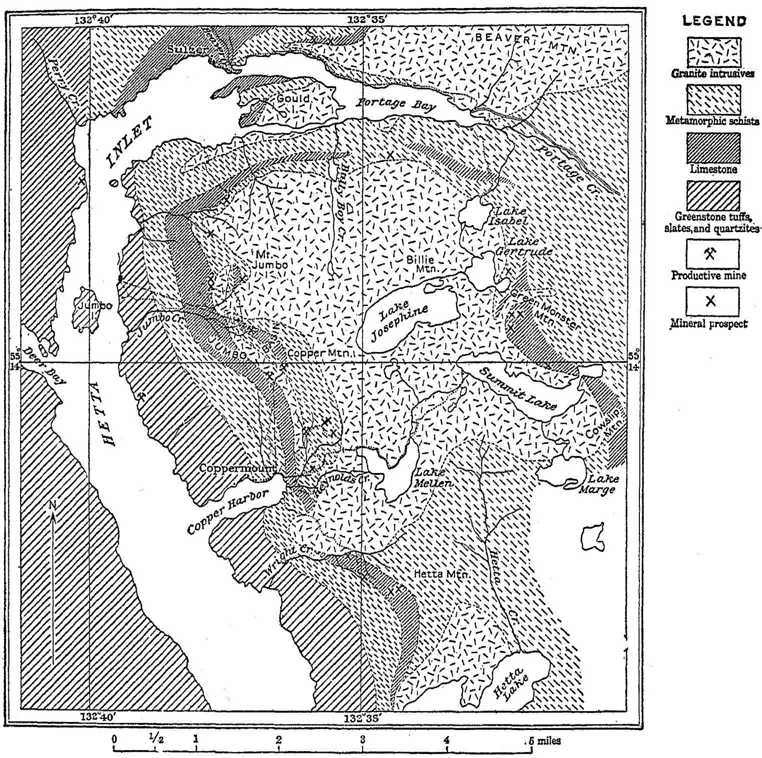


FIG. 95.—Geologic map of Copper Mountain Region, Prince of Wales Island, Alaska. After Wright. (*By permission of the Macmillan Company, from Ries' Economic Geology.*)

ated with pyrrhotite, pyrite and magnetite with a gangue of amphibole and feldspar. Fissure veins and disseminated ores are also encountered. (See Fig. 96.)

(2) On Prince William Sound the ore is chalcopyrite disseminated through the metamorphic schists. The ore is associated with pyrite and pyrrhotite in cavity fillings. Also as replace-

ment deposits of impregnations in a shear zone in slates and graywackes.

(3) The Copper River district is near Mount Wrangell. The ores are chalcocite and bornite associated with pyrrhotite and magnetite as dissemination deposits in masses of greenstone.

(4) The Kotsina district is situated some little distance inland from the coast. The chief copper mineral is chalcocite.

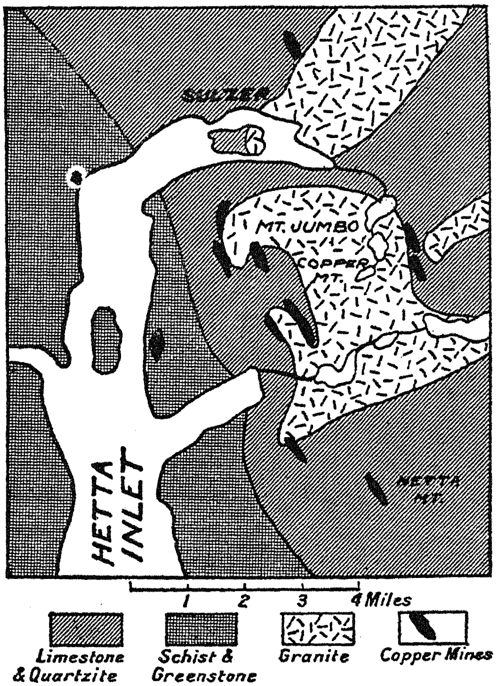


FIG. 96.—Sketch map of the Copper Mountain district, Prince of Wales Island, Alaska. (*After F. E. and C. W. Wright, U. S. Geological Survey.*)

The ore is found as replacement deposits in the Triassic limestones associated with the earlier greenstones.

The Geographical Horizon.—Copper ores are not restricted to the rocks of any particular age. They occur in all horizons up to the Tertiary, but the ores are especially abundant in the older formations as the pre-Cambrian, Cambrian and Ordovician terranes.

Methods of Extraction. (1) *The Reduction Process.*—Copper is extracted from its carbonates and oxides by means of roasting

the ore in the presence of carbon. The following equations indicate the process as applied to cuprite and tenorite:

$$Cu_2O + C = CO + 2Cu$$
$$2CuO + 2C = 2CO + 2Cu.$$

The two carbonates, malachite and azurite, when roasted lose both water and carbon dioxide. The resulting product is the black oxide of copper, which in the presence of carbon yields metallic copper and carbon monoxide according to the equation given under tenorite.

(2) *The Oxidation Process.*—The sulphides of copper are roasted in large beds in the open air to volatilize the sulphur content as sulphur dioxide. These beds at the Ely mine at Copperfield in Vershire, Vermont, in the days when 1700 miners were employed at one time, were approximately 50 rods in length and about 4 ft. high. The copper by the open-air roasting was largely converted into the oxide. In the later years at the same camp the ore was roasted in a blast-furnace and the sulphur passed out of the chimney flues as sulphur dioxide. The concentrated and oxidized ore is then roasted with carbon or coke and copper matte is obtained. From the matte by further treatment blister copper is obtained, from which arsenic and antimony are removed by volatilization, if present, then the lead, then the iron, and the copper is finally obtained in a comparatively pure state and cast into blocks weighing about 200 lb.

(3) *The Chlorination Process.*—When copper ores contain about 3 per cent. of copper, too poor for the extraction of copper by roasting alone, they are sometimes calcined with about 15 per cent. of common salt. This converts all the copper into the chloride which is readily soluble in water. The fused mass is then leached with water and the resulting solution of the chloride of copper is drawn off into precipitating tanks. Scrap iron is often used to reduce the copper to the elemental state.

(4) *The Electrolytic Process.*—This process consists in bringing the copper into solution and reducing the metal by electrolysis. The process is applicable to the forsaken residues around many old copper mines. The cost of reduction is said to be about one-half cent per ton of solution.

(5) *The Scrap-iron Process.*—The Rio Tinto mines in Spain furnish many pounds of copper by simple reduction with scrap iron. At Wicklow, Ireland, at one time about 500 tons of scrap

iron was introduced into the mine waters bearing copper sulphate. In one year the iron was all dissolved. Each ton of iron produced from one and a half to two tons of cement copper, a kind of reddish mud containing 1600 lb. of copper in every ton. There are many other methods of treating copper ores as suggested and described in "Modern Copper Smelting" by E. D. Peters.

Large quantities of pyrite containing small amounts of copper are annually imported from Spain. The sulphur content is used in the manufacture of sulphurous and sulphuric acids. The residue is concentrated and smelted into pig copper which is electrolytically refined. Small amounts of copper in these Spanish ores can be extracted with profit in America. The refineries also treat ores imported from Mexico, Australia, Tasmania and Japan. There is an interesting incident cited by James Douglas where copper matte was bought at full price in Tennessee, transported by rail to Norfolk, Virginia, reshipped to Tampico, Mexico, carried half way across the Republic, used in the extraction of gold and silver, concentrated into black copper oxide, brought back again by rail and water to New Jersey, and electrolytically refined with profit. The low transportation rates and precipitation by electrolysis at the expenditure of less than 1/2 cent per pound makes this possible. Chilian copper bars stored in English warehouses have been shipped to the United States refineries for electrolytic treatment, and the refined product exported to Europe. The refineries can not only successfully compete with those abroad, but with them also in their own marts of trade, for copper refining costs less in America than in Europe because our refineries are larger, better equipped, and more economically managed.

Uses of Copper.—The uses of copper in the various arts and industries are almost too familiar to mention. Some of the salts of copper are used in medicine and the sulphate of copper is widely utilized in the purification of water supplies for villages and cities. It destroys the *euroglena americana* and other organisms in the storage waters that give to them a fishy taste and odor.

Copper is used extensively in the various forms of electrical apparatus, electric traction and power, in electrotyping, electric lighting, telegraph cables, in flashing around chimneys and in gutters. The alloys of copper are of great technical value and

capable of wide industrial application. Copper has been used as a medium of exchange for many generations. In coinage, gold and silver are too soft to resist abrasion. They are each alloyed with copper in such proportions that the color and malleability are not seriously impaired, while the hardness is materially increased. Copper is the hardening metal in the gold and silver of jewelry. With platinum copper alloys in all proportions. Cooper's gold, which so closely resembles 18 carat gold and for which it is so largely substituted, sometimes contains over 80 per cent. of copper. Mirror metal has 57.85 per cent. copper and pen metal 13 per cent. of copper.

The brasses are important alloys of copper and zinc. They range from 95 per cent. of copper and 5 per cent. of zinc to 40 per cent. of copper and 60 per cent. of zinc. The most important brasses are those of about 40 per cent. of copper and 60 per cent. of zinc. Some of these have a tensile strength of 40,000 lb. to the square inch. English brass consists of 2 parts of copper and one of zinc. Muntz metal consists of 3 parts of copper and one of zinc. Dutch brass consists of 5 parts of copper and one of zinc. Brazing metal of 9 parts of copper and one of zinc. Naval brass which is so extensively used in condenser tubes consists of 70 per cent. copper, 29 per cent. zinc, and one part of tin.

The bronzes are important alloys of copper and tin. Various forms of bronze were used by the ancient Greeks and Romans. Relics of bronze have been found in the Lake dwellings of Switzerland. The bronzes of the greatest technical value carry over 80 per cent. of copper. Those containing about 50 per cent. of copper are called speculum metal, which is used for widely different purposes than the regular bronzes, as, for instance, the silvering of glass reflectors and the specula for reflecting telescopes. Gun metal consists of 9 parts of copper and 1 part of tin. Bell metal consists of 80 per cent. copper and 20 per cent. of tin. Silver is sometimes added in small quantities to bell metal to increase its sonorous quality. Machinery brasses and bronzes consist of alloys of copper, tin and zinc.

Copper is used largely as bearing metals. One of these consists of 70 per cent. copper, 15 per cent. of tin, and 15 per cent. of lead. It is well known and widely utilized. Another consists of 7 parts of copper and one of tin. Still another of 65 parts of copper and 35 parts of tin. Hot boxes upon railroad trains often

arise from the segregation of the copper in the alloy into spots. Hot boxes may arise from three causes: (1) Segregation of the metal into spots capable of producing intense heat through friction; (2) too coarse a crystalline structure of the alloy, and (3) the presence of dross. Imperfect lubrication plays a very minor part.

Aluminum bronze as the name implies is an alloy of copper and aluminum. These various alloys are widely used in the arts. One of these consist of 90 per cent. copper and 10 per cent. of aluminum. If the percentage of aluminum falls below 5 or rises above 10 the bronzes are of little techincal value.

Copper amalgams are used wherever a change from a plastic to a solid state is desired. They are used to some extent in filling teeth.

One of the new uses to which copper has been successfully applied is the coating of railroad passenger cars, forming a substitute for paint and varnish. The sheet copper used on the sides is 0.012 in. in thickness and fastened to the wood by invisible screws. When in place the copper is washed with a weak acid solution, and the shellaced or lacquered.

Copper oxide has come into a new use in the painting of the bottom of ships. This forms a substitute for copper sheathing. Copper oxide is used in refining petroleum. The gas is absorbed by the copper oxide forming the sulphide of copper and water. The oxide is regenerated by roasting the sulphide. Cupric oxide is used in the Edison LeLande electric battery, which consists of a zinc element and one of copper oxide. The battery is said to be one of the most economical and durable in the American market. Cupric oxide is used also in coloring glass, the green and the blue depending largely upon the manipulation. Copper oxide is used in the tile and glazed brick industries for decorative effect. It is also used in the oxidation of organic matter for it is an efficient oxidizing agent under heat.

The output of copper in 1906 was $177,595,888. The smelter production of copper in 1911 in the United States exceeded 1,000,000,000 lbs.

Cadmium: Its Properties, Occurrences and Uses

Properties.—Cadmium, symbol Cd, is a bluish white, ductile, malleable and sectile metal. It tarnishes upon exposure to the

atmosphere, but when freshly cut its luster is very brilliant. It is readily soluble in the mineral acids. Its specific gravity is 8.6, melting point, 321.7° C., and its atomic weight is 112.4.

Ores of the Metal.—Cadmium does not occur free and uncombined in nature. It must, therefore, occur only in combination. The one important mineral is the yellow sulphide, greenockite, CdS. This ore occurs in association with sphalerite, ZnS, and as an incrustation on calcite, $CaCO_3$. The resinous luster of cadmiferous sphalerite has often been attributed to the presence of greenockite. Cadmium occurs also in combination with carbonic acid as cadmium carbonate, $CdCO_3$, and in smithsonite, $ZnCO_3$.

Origin of the Ores.—Cadmium ores are always of secondary origin. They are deposited from solution with the ores of zinc by the action of alkaline sulphides upon ascending solutions of the metal. The metal may also be precipitated as the sulphide with the sulphide of zinc by the action of organic matter. By the alteration of cadmiferous sphalerite in the upper level of ore bodies, cadmiferous smithsonite would be formed as a surface deposit.

Geographical Distribution.—Greenockite occurs in association with zinc in Arkansas, Kansas and Missouri. It occurs also in Pennsylvania where it is associated with the yellow zinc carbonate known by the miners as "turkey fat."

Geological Horizon.—The ores of cadmium are not confined to any particular geological horizon. They are, in fact, the same as that of zinc.

Method of Extraction.—The manufacture of metallic cadmium was begun for the first time in the United States in 1907 by the Grasselli Chemical Company, Cleveland, Ohio. The process is fractional distillation in iron retorts. The brown fumes that distill over in the first product from the refining of zinc are cadmium oxide, CdO.

Uses of Cadmium.—Cadmium is used to some extent in the manufacture of yellow pigments. The iodide and bromide of cadmium are used in photography. Cadmium is used extensively in the manufacture of sterling silverware. In this industry 0.5 per cent. of cadmium imparts malleability to the alloy and prevents the formation of blisters. Cadmium alloys all possess a low melting point. Many of these alloys of cadmium, bismuth, lead and tin in varying proportions melt between 60° and 100°. Stereotype metal consists of 50 per cent. lead, 27.5 per cent. tin

and 22.5 per cent. cadmium. Cadmium is used also in the britannia ware and soldering German silver. A soft solder consisting of 37 parts lead and 63 parts tin, and 8 parts cadmium fuses at 36°. Cadmium is used also in cadmium plating, especially with tin, where the coating is hard and takes a high polish. Cadmium is used somewhat with mercury as an amalgam in the filling of teeth. Cadmium salts are well known in the chemical trade.

CHAPTER VI

USEFUL METALS CONTINUED (GROUP II, SUBGROUP B)

ARSENIC, ANTIMONY, TIN

Arsenic: Its Properties, Occurrence and Uses

Properties.—Arsenic, symbol As, is a steel gray, brittle metalloid. It crystallizes in the hexagonal system in regular acicular prisms, and begins to volatilize at 100° with a characteristic garlic odor. It is a good conductor of heat and electricity. In its salts it suggests an acid, and in its alloys a metal. It is seldom that it plays the rôle of a base. It is soluble in HCl; specific gravity, 5.8, melting point, at red heat, and its atomic weight is 75.

Ores of Arsenic.—*Native arsenic,* 100 per cent. As. Often alloyed with gold and silver, sometimes with bismuth and iron.

Realgar, AsS, 70.1 per cent. As. The only aurora red mineral entirely volatile before the blow pipe.

Orpiment, As_2S_3, 61 per cent. As. With honey yellow surfaces on its cleavage face.

Arsenopyrite, FeAsS, 46 per cent. As. A sulph-arsenide of iron.

Arsenolite, As_2O_3, 75.8 per cent. As. A white oxidation product of other ores.

Löllingite, $FeAs_2$, 72.8 per cent. As.

Leucopprite, Fe_3As_4, 62.1 per cent. As.

Smaltite, $CoAs_2$, 71.8 per cent. As.

Niccolite, NiAs, 76.1 per cent. As.

Allemontite, $SbAs_3$, 65.2 per cent. As.

There are also many arsenates of the useful and rare metals, also the arsenate of calcium.

Origin of the Ores.—Arsenic is one of the rarer elements, although widely distributed in nature. It has been found in the nails of man, in the horns and hoofs of cattle, in the mane and hoofs of horses, and in the bristles and hoofs of hogs. According to F. W. Clarke, traces of arsenic have been observed in

organic matter and found as a common ingredient of thermal springs. It has been detected by Daubreé and Gautier in sea water. Native arsenic may result from the decomposition and reduction of other ores of arsenic. W. H. Weed and L. V. Pirsson report both realgar and orpiment from the hot-spring deposits of Yellowstone Park. G. F. Becker observed the sulphides of arsenic in a sinter at Steamboat Springs, Nevada. They occur in seams in a sandy clay beneath the lava of Iron County, Utah. Arsenic has been found in calcite in California, and orpiment has been deposited in quartz crystals in Bosnia. In Tyrol the sulphides of arsenic occur in association with gypsum. Near Naples arsenic occurs as a product of volcanic sublimation. Realgar and orpiment have both been found as sublimation products of burning coal mines.

The ready solubility of the sulphides of arsenic allows transportation to a considerable distance from the original ore bodies only to be reprecipitated through various agencies. Arsenopyrite is sparingly soluble in warm waters and from these solutions it is known to recrystallize. Arsenolite, the white oxide of arsenic, is an oxidation product of the native element or of other ores of arsenic. Percolating arsenical solutions acting upon the carbonates of other metals or upon calcite would give rise to the arsenates of those metals or the arsenate of calcium.

Character of the Ore Bodies.—Native arsenic occurs in veins in the crystalline rocks and the older schists. It is often associated with ruby silver, antimony and the sulphide of zinc. The sulphides occur in fissure veins with silver and lead minerals, also in seams in sandy clays and as small crystals embedded in clay. (See Fig. 97.)

Arsenopyrite is by far the most important ore. It occurs in well-defined fissure veins in beds, in threaded bands, and as impregnation deposits in the country rock.

Geographical Distribution.—As already noted the arsenical minerals are widely distributed in nature but the valuable commercial occurrences are few. In the United States the areas fall into three distinct belts: (1) The Appalachian belt; (2) the Cordilleran district, and (3) the Pacific Coast belt.

(1) The Appalachian belt stretches from Alabama on the south in a northeasterly direction to Newfoundland. According to H. Ries, one of the best known deposits of arsenopyrite occurs at Rewald, Floyd County, Virginia. The ore deposit forms a

series of lenses in a quartz-sericite schist. The principal lens is about 3 ft. wide at the surface but thickens to 14 ft. at a depth of 120 ft. An unworked deposit of arsenopyrite also occurs in the same state in Rockbridge County in association with pyrite and cassiterite in quartz-greisen bearing tin veins.

At Carmel, New York, arsenopyrite occurs as a banded deposit in gneiss, in two zones 20 ft. wide intersecting each other at an angle of 60 degrees. At Braintree, Vermont, there is a 4-ft.

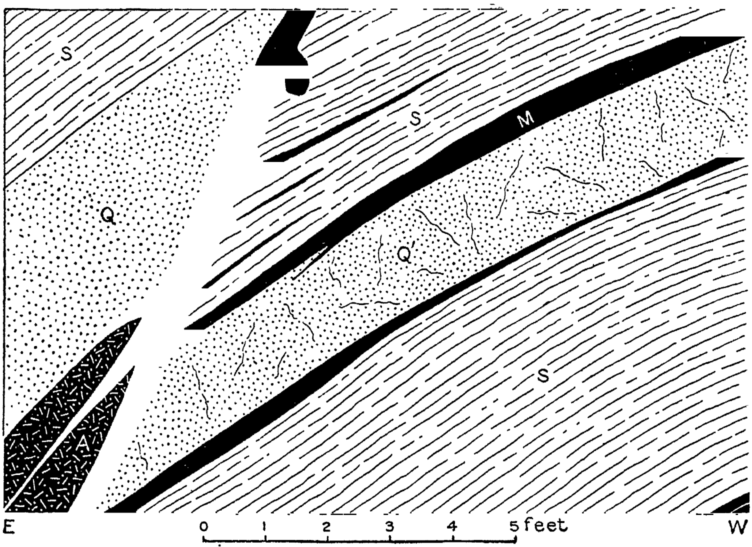


FIG. 97.—Vertical section in short drift near end of upper tunnel, Great Gluch mine, Mineral Ridge, Nevada. *A*, Alaskite; *Q*, quartz; *Q'*, quartz (feldspathic, much broken); *S*, shaley limestone; *M*, mispickel ore. Mispickel occurs along a fault zone on both sides of the crushed quartz especially abundant on the hanging wall side. (*After J. E. Spurr, U. S. Geological Survey.*)

vein of arsenopyrite traversing Ordovician limestones and schists. Arsenopyrite occurs in fine crystallizations in gneiss at Franconia, New Hampshire, also at Jackson and Haverill, New Hampshire.

(2) The Cordilleran district carries many gold, copper and other mineral deposits that contain arsenic but in the roasting and smelting of these ores the arsenic is not saved as a by-product but is allowed to pass off with the furnace smoke and gases.

(3) The Pacific coast belt has two chief representatives.

One in the arsenical gold ores of California and the other at Monte Cristo, Washington, where auriferous sulphides, realgar and orpiment are mined and the white arsenic of commerce is manufactured.

At Deloro, Ontario, arsenopyrite occurs in large beds with a quartz gangue cutting pre-Cambrian schists. This deposit has been successfully worked for some time both for gold and for the arsenic which is converted into white arsenic. The ore also occurs in fissure veins with a quartz gangue in Grimsthorpe, Ontario. The ores here are not so highly auriferous as at Deloro.

According to Thomas and MacAlister, the presence of arsenical pyrites in some of the largest tin mines of the west of England is remarkable. The lodes belong to the pneumatolytic group of ores. Under similar circumstances the ore is found in the tin mines of Saxony and Bohemia. Workable deposits of arsenical ores are found also in Turkey.

Geological Horizon.—Arsenical ores are found from the pre-Cambrian to the Ordovician in the modes of occurrence suggested. Recent arsenical deposits are not of workable dimensions.

Methods of Extraction. *The Roasting Process.*—Native arsenic and its sulphides are crushed and heated in long earthenware retorts into whose mouths are fitted earthenware receivers. The arsenic volatilizes, and condenses as a compact crystalline solid. This product is redistilled in a current of air when the arsenic is converted into the white oxide, the form in which it generally appears in the marts of trade.

The Electric Furnace Process.—The Arsenical Ore Reduction Company of Newark, New Jersey, has established an electrical furnace for the treatment of arsenopyrite, commercially known as mispickel. The ore is subjected to the intense heat of the furnace in an atmosphere of nitrogen. The iron present in the arsenopyrite unites with the sulphur in the formation of a ferrous sulphide, which is drawn off as a liquid mass. The arsenic is distilled and condensed as a white powder. The cost of the treatment of such ores with 46 per cent. of arsenic is estimated to be less than 25 cents per hundred weight.

Sources of the Arsenic of Commerce.—(1) Arsenic is obtained as a by-product in the treatment of the ores from various tin mines, especially in England. (2) From tin, copper and tungsten ores intimately associated with arsenic. (3) From the treatment of

the waste heaps of exhausted copper mines. (4) Some mines are worked solely for the arsenopyrite which they contain. The mineral is then concentrated, not roasted, and sold direct to the refineries. (5) Some mines are worked for the arsenopyrite which is concentrated and manufactured into commercial white arsenic at the mine.

In the arsenic industry various samples of the roasted ore are analyzed in order to keep the product uniform in arsenic content. For any arsenic found above a fixed minimum the men are subjected to a reduction in their wages. Good work is the result. Arsenic is obtained from speiss that is formed in lead furnaces. This is said to have been the source of the arsenic sometimes present in sulphuric acid.

Uses of Arsenic.—Arsenical compounds have acquired great notoriety because murderers and suicides have successfully resorted to them to accomplish their foul designs. Their toxic nature has become so pronounced that not only the general public but scientific and medical circles have become accustomed to avoid such substances and to overlook some of the good qualities which arsenic possesses. The layman knows very little of the sources of the arsenic supply, of the manufacture of arsenical compounds, and of the properties of the finished product.

Arsenic is used in producing colors too extensively utilized for the public good. Potassium arsenite was formally used for tinting wall paper. This use is now practically controlled by law, only a minimum per cent. per square yard of wall paper is permissible. From dampness or other causes a mould is developed and hydrogen is set free which reacts upon the arsenical compound in the paper and forms the deadly arsenureted hydrogen, AsH_3.

Arsenic is used in the calico printing as a conveyor, or fixer, or both, of the aniline colors. It does not enter into the color largely if at all for it is washed out of the calico during the process of coloring. Some attempts have been made to recover the arsenic from the resulting solution but the processes instituted are too expensive. Realgar is utilized in the various red shades of fabrics, orpiment in the production of various shades of yellow. Grays may also contain arsenic. Perhaps the most dreaded of all colors on account of its arsenic is the terra cotta red. Various parties concerned directly in the manufacture of tinted papers and colored fabrics either mine or import, or both, realgar and orpiment for use as a pigment in their industries.

Arsenic is used in medicine in several forms. Liquor arsenicales is used in intermittent fevers, in rheumatism and nervous afflictions. White arsenic is used extensively in progressive, pernicious anemia. Two to four grains of arsenic form a fatal dose. Arsenic is used also in many embalming fluids. In arsenic eaters it clarifies the skin and imparts a rotundity to the body. It also strengthens the respiration, therefore, Marathon runners and mountain climbers have resorted to its use.

Fowlers solution is used to fatten horses and to give them greater speed in the race. It furnishes not only rotundity to the body, but also produces glossy, shiny hair.

Arsenic is used in many forms as a preservative. Ten parts of hot water or 30 parts of cold water will dissolve 1 part of white arsenic. The solution is a good wood preservative as it prevents both wet and dry rot. It is important in the treatment of railway ties, telephone and telegraph poles, and the timber of mines. Carpenters and builders use it in many forms of joints.

Arsenic is used extensively in agriculture. Hundreds of tons of arsenic are used annually as a weed killer. It is used extensively to prevent foot rot in sheep. The white arsenic is dissolved in water and poured into troughs 20 ft. long and 1½ ft. wide. The sheep are driven back and forth through the trough and then on to dry ground or floors that their feet may thoroughly dry. Arsenic is used for killing sheep ticks, both the sheep and lambs being dipped in a solution of white arsenic.

Arsenic is used as an insecticide as lead arsenate in the destruction of the gypsy moth. Large quantities of Paris green are manufactured annually to kill the Colorado beetles and their slugs; also the larvæ on currant bushes, rose bushes, and cabbages. In England the best crops of potatoes are always obtained in the vicinity of an arsenical plant. Arsenic successfully checks potato blight and in many modifications it is used for that purpose in America.

Arsenic is used in rat poison and fly paper. Much arsenic has been sent across the mountains of South America on mule back for the dressing of hides for exportation. It effectually prevents the attack of insects on the hides. It is used extensively in taxidermy, where the skins of fish, of beasts and birds are subjected to a thorough rubbing with white arsenic before mounting. It is used also in the preservation of moths, butterflies and larvæ.

Arsenic is used in the manufacture of glass, in the manufacture of certain alloys. Perhaps the most important of these is shot. The presence of 1 per cent. of arsenic renders the lead more fluid when heated, therefore, it more readily assumes the spherical form when dropped from the shot tower. The alloy upon solidification is much harder than pure lead, therefore, it has greater penetrating power. Its greater rotundity imparts swiftness and accuracy.

Arsenic with many metals renders them both hard and brittle. This is especially true of tin. When only a few thousandths of 1 per cent. of arsenic is present it renders both gold and silver brittle. Arsenic also hardens copper and renders it brittle. It is an injurious constituent of brass. Brass with 0.5 per cent. of arsenic cracks, breaks down, and will not roll. In fact it has refused to roll with 0.02 per cent. present. It increases the fluidity of brass, and with less than 0.02 per cent. decreases its ductility. Arsenical bronzes contain from 8 to 10 per cent. of arsenic. It is evident, therefore, that white arsenic comprises by far the larger part of the arsenic of commerce. If other forms are required as in the manufacture of colors, or in the various medicinal preparations the refined forms or the arsenical preparations are manufactured by those parties most concerned in their industrial application.

It is often stated that the arsenic industry is fraught with great danger of blood poisoning, and other evils to the employee. This appears to be an exaggeration. True it is that some operations can be conducted only by skilled workmen, who know what precautions have to be taken and how to take them. All work demands care, but especially where there is dust, as in the cleaning out of chambers, in grinding the white arsenic, and in filling the barrels. In these dusty operations the nostrils are kept plugged with cotton wool, and in cleaning out the flues the limbs are kept bandaged. In Cornwall and Devon, England, where these precautions are observed arsenical poisoning is rare.

Among the new industries that have recently been developed in the United States is the manufacture of white arsenic by the Puget Sound Reduction Company at Seattle, Washington. The Company recovers the arsenic from the Monte Cristo, Washington ores. In 1907 a company was incorporated at Carmel, Putnam County, New York, for mining, concentrating and exporting arsenopyrite.

Antimony: Its Properties, Occurrences and Uses

Properties.—Antimony, symbol Sb, is a tin white, extremely brittle metal. It is distinguished from all other metals, save bismuth, by its brittleness and from all the other metals in the character of its salts. In many respects these are more closely allied to the salts of the metalloid arsenic than to those of the true metals. It fuses easily before the blow pipe forming dense white fumes of the white oxide, Sb_2O_3. If heated intermittently there appears upon the button prismatic crystals of artificial valentinite. The metal does not tarnish at the ordinary temperatures. It is soluble in concentrated HCl; specific gravity, 6.7, melting point, 630.5° C., and its atomic weight is 120.2.

Ores of Antimony.—*Native antimony,* Sb, 100 per cent. Sb. Often alloyed with silver, arsenic and iron.

Stibnite, Sb_2S_3, 71.4 per cent. Sb. Massive or in reticulated crystals.

Kermesite, $2Sb_2S_3,Sb_2O_3$, 75 per cent. Sb. A cherry-red prismatic mineral.

Valentinite, Sb^2O^3, 83.3 per cent. Sb. Occurring in white orthorhombic crystals.

Senarmontite, Sb^2O^3, 83.3 per cent. Sb. Occurring in white isometric crystals.

Cervantite, Sb^2O^3,Sb^2O^5, 78.9 per cent. Sb. Yellow or yellowish-white in color.

Antimony occurs also with many lead ores as galenite. From this mineral the extraction of the antimony is somewhat difficult. It occurs also with several silver ores. It is also associated with some gold ores.

Origin of the Ores.—Native antimony is derived from the reduction of the other ores of the metal. Stibnite is slightly soluble in water at 80° C., and its recrystallization from such a solution is perceptible. Stibnite has been reported from Tuscany as a product of solfataric action. According to F. W. Clarke, this mode of deposition is ascribed to the fact that the metal forms easily volatile compounds. In most cases stibnite has been deposited from alkaline solutions which have the power to dissolve silica. In this manner solutions bearing antimony may be transported a considerable distance from the original ore body. The same alkaline solutions have the power to dissolve silica, and this explains the presence of quartz as the most important gangue mineral for stibnite.

According to J. D. Dana, the amorphous brick red mineral metastibnite, Sb_2S_3, occurs with cinnabar deposited upon siliceous sinter at Steamboat Springs, Nevada.

The oxysulphide results directly from a partial oxidation of stibnite. Valentinite and senarmontite are oxidation products of other ores of antimony. Valentinite crystallizes from solutions above 100° C. and senarmontite solidifies at the lower temperatures.

Character of the Ore Bodies.—Antimony ores occur most abundantly in fissure veins traversing both the igneous and the sedimentary rocks. They occur also in flats, pitches, and as impregnation deposits. The gangue minerals in the order of their importance are quartz, calcite, and barite. The associated minerals are the gold and silver ores, cinnabar, galenite and sphalerite.

Geographical Distribution.—In the United States small quantities of antimony ores are found in the Appalachian belt but none of the occurrences appear to be of commercial significance. These small deposits may be observed at Soldier's Delight, Maryland; Lyme, New Hampshire.; and Carmel, Maine. In southeastern Arkansas stibnite occurs in bedded veins traversing Carboniferous limestones and shales. In Idaho auriferous antimony ores occur in flats and pitches near Burke, Shoshone County. The gold content is reported as $20 per ton of ore. In Nevada, which has been an important producer, exceptionally pure stibnite occurs with little gangue mineral near Austin in well-defined contact fissures between shale which forms the foot wall and calcareous sandstones and lime porphyries. In Utah it is disseminated through conglomerates and sandstone along the planes of stratification. In California stibnite occurs in well-defined fissure veins with a quartz gangue.

In York County, New Brunswick, auriferous and argentiferous native antimony and stibnite are found in fissure veins with quartz and calcite gangues traversing black slates.

According to Thomas and MacAlister, the Algerian deposits occur in the Province of Constantine in the neighborhood of Jebel Hammamet. The ore, which exists chiefly as oxide, is found in irregular layers running parallel to the beds of black limestone of Lower Carboniferous age with which it is associated. These ores were at one time considered as simple sedimentaries, deposited contemporaneously with the enclosing limestones. It appears,

however, that metasomatic replacement of the limestone more closely approximates to the true explanation of the facts observed.

According to K. Yamada, antimonial ores occur on the island of Shikoku in lodes in a sericite schist with quartz as the chief gangue mineral. Magnificient groups of splendent crystals of stibnite that have found their way into many museums occur in the extensive antimony mines in the Province of Iyo on the same island.

In the order of their importance, Bolivia, France, Hungary and Spain are the commercial producers of antimony.

Geological Horizon.—The ores of antimony are not confined to any particular geological horizon. Those in the Appalachian belt are associated with the older crystalline schists. Those in Arkansas occur in the Carboniferous. In Tuscany antimony lodes occur between the Permian shales and the Eocene limestones.

Methods of Extraction. (1) *Roasting.*—Owing to the low fusion point of stibnite, melting easily in a candle flame, the ore is crushed and roasted, the liquated sulphide drawn off in inclined iron pipes. The sulphide is then roasted in a current of air when the oxide, Sb_2O_3, is formed. The oxide is then reduced to the metallic state by common salt or scrap iron. The crude metal thus obtained is further refined by roasting with scrap iron. The following reaction may obtain, $Sb_2S_3+3Fe=3FeS+Sb_2$. The process is applicable to the sulphides of the metal.

(2) *The Crucible Method.*—Native antimony is crushed and heated in large graphite crucibles with scrap iron. If any sulphur is present it unites with the iron in the formation of the sulphide of iron as represented in the above equation. The antimony by its higher specific gravity sinks to the bottom of the crucible as a bluish-white crystalline metal. The process is applicable to the native metal and to the sulphide, stibnite.

(3) *The Wet Method.*—Stibnite is dissolved in hot concentrated HCl and precipitated from its solution by iron or zinc. It may also be precipitated by pouring into water when the oxychloride, SbOCl is formed.

(4) *The Reduction Process.*—The oxides of antimony, valentinite and senarmontite, may be reduced to the elemental state by reduction with carbon.

$$Sb_2O_3+3C=3CO+Sb_2.$$

(5) *Electrolytic Method.*—The electrolytic process may also be utilized in the production of metallic antimony. The process of refining metallic antimony is very difficult and few understand the details of modern practice in the industry.

Uses of Antimony.—Antimony is used extensively in alloys. In general a mixture of antimony with other metals renders them more lustrous, hard, and somewhat brittle. The alloys of antimony, like those of bismuth, expand upon cooling, therefore they make fine, hard, sharp castings. An alloy consisting of 86.5 per cent. lead and 13.5 per cent. antimony is 4 times as hard as pure lead. An alloy consisting of 35.86 per cent. lead and 64.14 per cent. antimony is 11.7 times as hard as pure lead.

Type metal consists of lead, antimony, and often tin in varying proportions. Ten varieties of type metal are well known. The first of the series consists of 75 parts lead and 25 parts antimony; another of 75 parts lead, 20 parts antimony, and 5 parts tin. Type metal must cast readily and be capable of taking sharp impressions. It must be hard enough to resist crushing in the press and so soft that its edges will not cut the paper in the process of printing.

Stereotype metal consists of 112 parts lead, 18 parts antimony, and 3 parts of tin; britannia metal, 140 parts tin, 9 parts antimony, and 3 parts copper; pewter 89.3 per cent. tin, 7.1 per cent. antimony, 1.8 per cent. copper, and 1.8 per cent. bismuth; argentite 85.5 per cent. tin and 14.5 per cent. antimony; the luster of the latter alloy so closely resembles silver that it is sometimes difficult to distinguish the white metal from the alloy that carries no silver. This alloy is used extensively in the silver ware of commerce.

Babbitt is the name applied to a wide series of antifriction alloys used extensively in the journals of cars, locomotives, and other rapidly moving machinery. It consists of antimony, tin and copper, with small amounts of lead, zinc, bismuth and nickel. The tin always exceeds 50 per cent. and the copper may be entirely replaced by antimony, or the antimony by copper.

Antimony alloys with aluminum in all proportions at a comparatively low temperature. With less than 5 per cent. of antimony the alloy is vastly superior to aluminum in hardness, tenacity, elasticity, and malleability. It is more sonorous when struck. It resists the corrosive action of the gases of the at-

mosphere better than many other alloys, or the pure metals themselves. If the proportion of antimony is increased the alloy is proportionately harder, but correspondingly weaker in tenacity and elasticity. If the antimony exceeds 10 per cent. the alloy crystallizes in beautiful laminæ. Both the melting point and the ease of corrosion increases with the antimony and strikes a maximum at the true aluminum antimonide, Al_2Sb_2. Its melting point is higher than that of steel but the melting point of its constituents is very low. It is not attacked by dry air at the ordinary temperatures, but at the higher temperatures it is oxidized. Under the influence of moist air at high temperatures the alloy is readily decomposed. If the per cent. of antimony be still further increased both the melting point and the corrodability of the alloy are proportionately decreased. The antimony aluminum alloy readily combines with other metals forming a complex series, some of which are susceptible of a high polish and capable of industrial application. The aluminum, nickel and antimony alloys and the tungsten, silver and antimony alloy are exceedingly important and remarkable for their intense hardness, tenacity and elasticity. The alloys of antimony with silver, aluminum, nickel and copper are susceptible of a high polish and capable of wide industrial application. The alloys of antimony with iron and steel, with or without nickel and chromium, are extremely fine grained, absolutely free from flaws, hard and tenacious. With copper alone 1 part of antimony in 1000 parts of the red metal will destroy all of its beneficent effects. With copper, it is one of the most dreaded of all impurities as it occasions cracks in the rolling of the metal. It also is an injurious constituent in the brasses and bronzes.

Antimonial lead or hard lead is an alloy of the two metals indirectly derived from the treatment of antimonial gold and silver ores. For antimonial lead there is a good demand. Much antimony in commercial tin, zinc, arsenic, and copper reaches the market as a by-product in the metallurgy of base bullion and is sold direct as an alloy.

Antimony is used in dying as a mordant for vegetable colors. It is used also in medicine. The most common form is known in commerce as tartar emetic, a tartrate of antimony and potassium. It has caused death when applied to the skin as a local irritant or vesicant. It has a nauseous and metallic taste. The sulphide, Sb_2S_3, has also been used in medicine. It is also

used as a pigment. The crude ore was crushed and used by the ancients for coloring the hair, eyebrows, eye lashes so as to increase the apparent size of the eyes.

Antimony plays an important part in the refining of gold. It is also used in the manufacture of matches and percussion caps. Antimony pentasulphide is a bright red pigment used in the manufacture of vulcanized rubber and in many forms of fireworks. Antimony trisulphide is a fiery red pigment used in certain paints. Antimony is used in the lining of lead chambers for the manufacture of sulphuric acid. It is also used in the manufacture of toys and in coffin trimmings. The soluble salts of antimony are powerful irritant poisons, and 0.092 of a gram has proven fatal.

Economics.—Antimony for the consumption in the United States is largely derived from four sources. (1) Hard lead obtained in the smelting of foreign and domestic ores; (2) imported regulus or metal; (3) imported antimony ores, and (4) domestic ores. Considerable quantities of antimony are also recovered from the drosses of old type metal and similar sources by firms making a speciality of this branch of metallurgy.

The reasons for the small production of antimony in the United States are: (1) The low price of the metal; (2) the low cost of production in foreign countries; (3) the distance of known American deposits from market; (4) extensive foreign deposits; (5) the difficulty in smelting the ores; (6) low ocean freight rates, and (7) the low duty on crude antimony.

Tin: Its Properties, Occurrence and Uses

Properties.—Tin, symbol Sn, is a white metal remaining untarnished in either dry or moist atmosphere. It is soft enough to cut with a knife, malleable enough to be beaten out into a leaf, and ductile enough to be drawn out into a fine wire. At a temperature a little below its melting-point it becomes brittle and can be powdered. The "tin cry" is emitted whenever the metal is bent. No other metal cries so distinctly. It results from the friction of the crystalline particles moving upon each other. This friction perceptibly evolves heat. Tin is insoluble in the strongest nitric acid, but ordinary concentrated nitric acid oxidizes tin to metastanic acid, H_2SnO_3. The metal is readily soluble in concentrated HCl. Its specific gravity is 7.3, melting point, 232° C., and its atomic weight, 119.

Ores of the Metal.—*Native tin*, Sn, 100 per cent. Sn. Often with gold copper, platinum and iridosmine.

Stannite, Cu_2S,FeS,SnS_2, 27 per cent. Sn. Sometimes known as "bell metal," on account of its bronze color.

Cassiterite, SnO_2, 78.67 per cent. Sn. The most important ore.

There are also a few rare tin minerals. Of these nordenskiöldine, a borate of calcium and tin, CaO, SnO_2, B_2O_3, is the most interesting from a mineralogical point of view for it connects tin with the important mineralizer boron.

Several varieties of cassiterite are known. If it occurs in crystals or in masses it is known as *tin stone*. If in forms radiating and fibrous closely resembling wood, it is called *wood tin*. If in warty aggregations it is called *toad's eye tin*. If in rounded grains of sand along the beds of streams it is known as *stream* or *placer tin*.

Origin of the Ores.—Native tin which is very rare occurs only in small quantities perhaps as a decomposition and reduction product of other tin minerals. It occurs in grains in New South Wales but its occurrence with gold in Siberia, in Bolivia, and at Guanajuato, Mexico, are all doubtful. The native tin reported from Bolivia is believed to be artificial.

The association of stannite in Cornwall, England, with pyrite and sphalerite, together with the occurrence of stannite at Zinwald in the Erzgebirge with sphalerite and galenite would imply the deposition of the minerals from solution. This sulphide so pronouncedly suggesting in its appearance varieties of "bronze" or "bell metal" is called by the miners bell-metal ore.[1]

Cassiterite is by far the most important source of the tin of commerce. It is both primary and secondary in its origin. According to F. W. Clarke, it has been repeatedly observed as a furnace product formed by the direct oxidation of tin. According to C. Doelter, cassiterite is perceptibly soluble in water at a temperature of 80°, but more soluble in the presence of sodium fluoride. He also observed some crystallization from such solutions. S. Meunier found 0.5 per cent. of cassiterite in an opaline deposit somewhat resembling geyserite, from a thermal spring in Selangor. J. H. Collins reports cassiterite as a cement in certain Cornish conglomerates, also as impregnation deposits in long buried horns of deer, as pseudomorphs after feldspar, as cappings on crystals of quartz, as fissure linings in quartz, as

an incrustation on an ingot of ancient tin, as a secondary crystallization on reniform masses of wood tin. F. W. Clarke regards all these as evidences or proof that the famous Cornish ores are of aqueous origin.

According to F. A. Genth, pseudomorphs of cassiterite after hematite occur at Durango, Mexico. W. Semmons has also described the presence of cassiterite as a concentric coating on bismuthinite.

According to Thomas and MacAlister, cassiterite occurs as an original constituent of a few granites and acid volcanic rocks diffused more or less uniformly through the rock mass, but par-

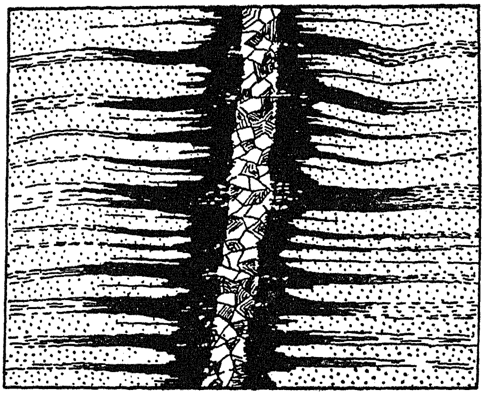


FIG. 98.—Vein of Cassiterite, quartz and tourmaline, traversing Paleozoic slates which consist of alternate bands of siliceous and argillaceous materials, Belowda Beacon, Cornwall, England. (*After Thomas and MacAlister's Geology of Ore Deposits.*)

ticular as inclusions in mica. Such primary segregations they regard as insufficiently large to be of direct economic value, but they may ultimately yield rich alluvial deposits.

The detrital deposits bearing tin are derived from the disintegration and wearing away of the acid intrusives and contact metamorphic rocks in which the tin lode occurs, and its presence in the placer gravels at no considerable distance from its original home to the transporting and sorting power of water. The ores of tin appear to occur as primary segregations, as pneumatolytic deposits, as metasomatic replacement deposits, and as detrital deposits.

Character of the Ore Bodies.—Cassiterite occurs as a primary segregation in the acid intrusives. It is found in fissure veins traversing granites, pegmatites, gneisses, porphyries, mica schists, chlorite schists, etc. Its home is often in veins of pegmatite associated with lithium bearing minerals as tourmaline, lepidolite, zinnwaldite and spodumene. This type of formation is pronounced in Maine, the Carolinas, the Black Hills, and in South Africa.

The second type of formation might lead to the conclusion that cassiterite is a product of secondary deposition. It is found in veins, beds, and stocks in association with quartzose, crystalline schists, and even traversing shales. (See Fig. 98.) Penrose has reported tin in the Malay Peninsula as occurring in beds in limestones and sometimes even in sandstones.

The most important mode of occurrence is in quartz veins traversing granites and pegmatites. The granite has become greisenized, that is, orthoclase has altered to lepidolite and zinnwaldite with topaz and tourmaline as associated minerals. The presence of minerals bearing boron and fluorine, together with the greisenization of the granite walls would lead to the conclusion that cassiterite may be formed by the injection of vapors bearing tin and the well-known mineralizers fluorine and boron. Fluorine is able at a high temperature to form a volatile compound with tin, which at lower temperatures and in the presence of steam would be decomposed into the oxide of tin and hydrofluoric acid according to the following equation, $SnF_4+2H_2O=SnO_2+4HF$.

Geographical Distribution.—There are five distinct belts of tin-bearing minerals in the United States, but none of them have assumed the proportions of a large producer. (1) The Appalachian belt; (2) the Black Hills district; (3) the Cordilleran section; (4) the Pacific Coast belt, and (5) the Alaskan district.

(1) *The Appalachian Belt.*—Numerous deposits of cassiterite occur in this belt which stretches from Alabama to Maine. In Maine tin ores occur in Hebron, Paris, Stoneham and Winslow. In Massachusetts cassiterite occurs in Chesterfield and Goshen associated with albite and tourmaline. In Virginia it is found in Rockbridge County with wolframite. The most promising field in this belt lies in the Carolinas. According to L. C. Graton and H. Ries, it stretches from near Gaffney, Cherokee County, South Carolina, across parts of Cleveland and Gaston

Counties, North Carolina, to Lincolnton, a distance of about 35 miles. The ore is irregularly distributed in pegmatite dikes traversing the metamorphic sedimentaries. Both the acid and the basic intrusives are present. The acid intrusives is the home of the cassiterite (see Fig. 99).

(2) *The Black Hills District.*—This field represents the most important occurrence of tin ores in the United States outside of Alaska. The ore is of three types. In quartz veins, impregnation deposits, and in placers. The last results in the normal disintegration of the associated tin-bearing rocks and the con-

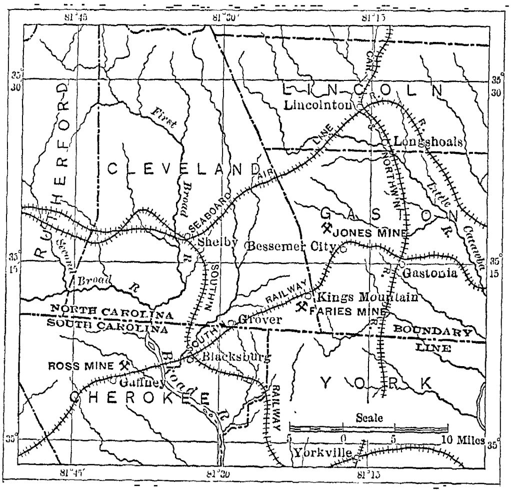


FIG. 99.—Sketch map showing the location of the Carolina tin belt. After Graton. (*By permission of the Macmillan Company, from Ries' Economic Geology.*)

centration of the stream tin through the sorting power of water. The placers carry the purest tin ores, for the other ores of lower tin content associated with the lode deposits have become oxidized at or near the surface. The ore occurs with wolframite and scheelite.

(3) *The Cordilleran Section.*—A few reports of the presence of cassiterite have been given for this district but the deposits are not large. It occurs, however, near Dillon, Montana, and in Crook County, Wyoming.

(4) *The Pacific Coast Belt.*—The Temescal tin mines are situated near the northern end of the San Jacinto estate in San

Bernadino County, California. The principal vein varies from a few inches to 8 ft. in width. In 1892 this mine was a producer of pig tin and bid fair to be of considerable commercial importance. It has, however, since that date been only a small producer.

(5) *The Alaskan Belt.*—In this district tin occurs in lodes and placers in the Seward Peninsula. According to F. L. Hess, the ores occur: (1) In quartz veins traversing phyllite schists; (2) in quartz porphyry dikes traversing limestones; (3) in disseminations in the greisenized granitic rocks. The ores are associated with calcite, fluorite and the lithium mica, zinnwaldite. A. H. Fay, (*Trans.* A. I. M. E., 1907) mentions one deposit as a contact between limestone and granite associated with much tourmaline. This area bids fair to be of some commercial significance.

Foreign Countries.—Two foreign deposits of tin ores are worthy of special consideration for they have been the largest producers of this useful metal. The first of these is Cornwall and Devon, England. The second is found in the Federated Malay States.

According to Thomas and MacAlister, the tin deposits in the former district are intimately associated with five large granite batholiths. Two of these at West Cornwall, England, are intruded in sediments of Ordovician age. Two in central and east Cornwall, in rocks of Devonian age. One in Devonshire in terranes of both Devonian and Carboniferous age.

The association of tin and copper ores are better illustrated at Cornwall, England, than in any other locality. The association of the tungsten and arsenic minerals with those of copper and tin is such that it leads to the conclusion on the part of some that the ores are of identical age.

The cassiterite portions of the lodes, however, occur in the older parts of the veins and appear to have been the first minerals formed. In other cases the cassiterite, chalcopyrite, arsenopyrite and wolframite are so intimately associated that it renders successive deposition a matter of doubt (Fig. 100).

The most important tin deposits of the world are found in the Federated Malay States. The leading states in production are Selangor, Perak, and Pahang. According to the State Geologist, Scrivenor, the origin of the tin lodes and their association with greisenized granite is akin to those in England. However, much of the tin mined is found in placers. The Kinta Valley is one

of the most important fields. This valley is about 40 miles in length, and averages about 15 miles in width. The amount of tin in some deposits is sometimes 20 per cent. The tin-bearing

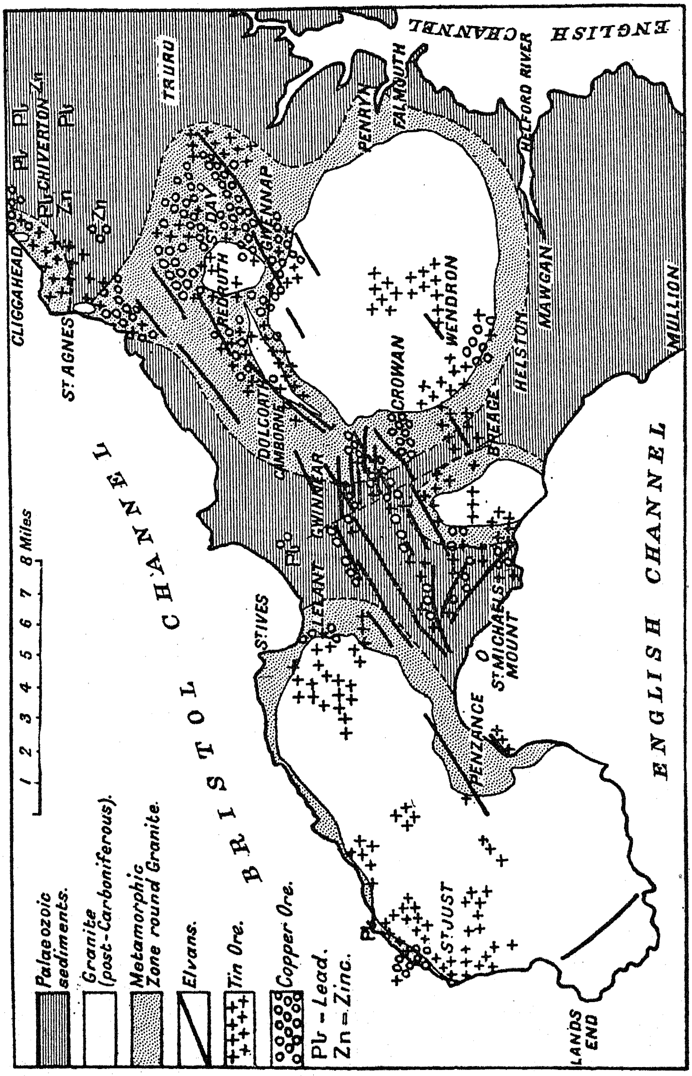


FIG. 100.—Geologica map of West Cornwall, England, showing the relation of the axes to the granites, elvans, and contact deposits. (*After Thomas and MacAlister's Geology of Ore Deposits.*)

alluvium is called *karang*. This material is often cemented together by limonite.

The *kong* is the term applied to materials having two modes of

origin. In one case it implies the kaolinized pegmatites bearing some quartz. In the other it signifies a true detrital deposit. In Parak there occurs the Lahat pipe which consists of an irregular pipe-like body of cassiterite extending to a depth of several hundred feet. The pipe was originally a tin-bearing vein but subsequently became a course for surface waters. The adjacent limestone was taken into solution and transported elsewhere. The cassiterite fell into this solution cavity and was subsequently cemented into a somewhat brecciated mass.

According to Scrivenor, the detrital cassiterite deposits on the islands of Banka and Billiton occur in two different ways. In one case the tin is found on the hillsides and plains not far from

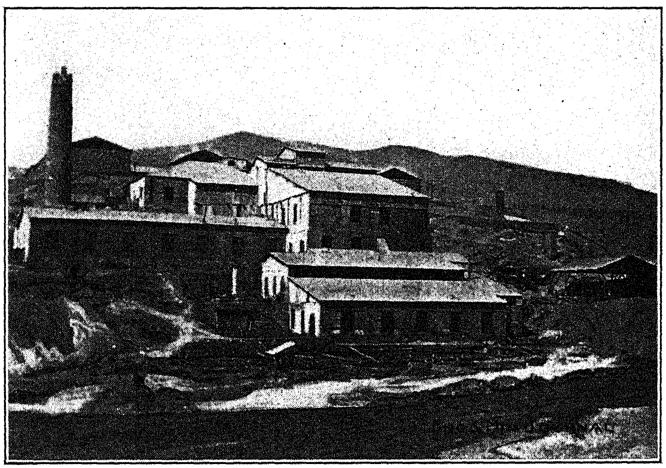


FIG. 101.—Reduction works of the Llallagua tin mine in Bolivia.

the lodes from which it was derived. In the other it is found in true valley detrital material which sometimes reach a depth of 50 ft. The tin-bearing portion of the placer lies in the lower 3 ft. of the deposit and is associated with topaz and tungsten minerals.

More than half of the world's supply of tin has been derived from the Federated Malay States and the islands of Banka and Billiton off Sumatra. The detrital deposits have been larger producers than the lodes.

A third foreign area of somewhat less importance is found in Bolivia. The deposits are of special interest because the ores are associated with lead, silver and bismuth minerals in a dacite

and trachite of recent volcanic origin. It is supposed to be of pneumatolytic origin and to provide an example of an intermediate type of veins between well-known tin veins with greisenized walls and the true veins of galenite with their associated sulphides (Fig. 101.)

Geological Horizon of Tin.—The ores of tin appear to be associated with the early as well as the late intrusives and to a limited extent with the later crystalline rocks.

Methods of Extraction. *The Smelting Process.*—Three steps are involved in the process. Calcining, washing, and smelting. The ore is crushed and washed to remove all earthy materials. It is then calcined to remove any volatile constituents that may be in the ore. If the cassiterite is mixed with stannite, the sulphide of tin, copper and iron, the sulphur passes off as sulphur dioxide. This may be reduced to elemental sulphur and sold as a by-product or converted into sulphurous acid which is so extensively utilized in the manufacture of paper by the sulphite process. If the ore contains arsenic the arsenic is conducted into the condensing flues of the reverberatory furnace where it is deposited as the white arsenic of commerce, collected and sold as a by-product. If antimony is present this metal will also be converted into the oxide which may be collected and sold as a by-product. If tungsten minerals are present the ore is treated with sodium carbonate which combines with the tungsten forming sodium tungstate. This compound is also sold as a by-product. In the process of calcining the copper is converted into the sulphate and the iron into its oxide.

The second step in the process is washing. This removes the copper sulphate as a solution from which the copper may be reclaimed by electrolysis. It also washes out the iron oxides and other minerals of lower specific gravity than the cassiterite. The cassiterite thus concentrated is smelted in a reverberatory furnace with carbon or powdered charcoal when impure metallic tin is obtained according to the equation, $SnO_2+2C=Sn+2CO$.

The metal now more or less alloyed with other metals is remelted, to separate it from the impurities. The molten metal is stirred with bits of green wood which cause a separation of scum or dross from the metal. The reduced metal is drawn into a cast-iron kettle, ladeled into moulds, and the blocks thus formed are known in commerce as block tin or pig tin.

In the process for the manufacture of tin as carried out at Corn-

wall, England, the ore is mined, hoisted to the surface (for some of these mines are being operated at a depth of over 1,300 ft.), transported to the stamp mill where it is broken down by hammers wielded by women, crushed in the stamp mill sufficiently fine to pass through a 40-mesh sieve, carried by water to the dressing floor where it is concentrated into black tin consisting of about 66 per cent. tin. This concentrated product is either sold direct as tin ore or is mixed with 20 per cent. pulverized charcoal and smelted.

Uses of Tin.—A large amount of tin is used in the manufacture of the tinware of commerce. The object to be plated is dipped in a bath of molten tin. The interior of the tin is a sheet of iron of varying thickness. The exterior of the tinware is a thin coat or film of tin. Between the two there is a thin band of alloy of tin and iron which serves to unite the two metals. When the surface of the iron is not perfectly smooth protuberances will perforate the tin and in a short time, through the oxidation of the iron, the dish will leak.

Tin is used extensively in the manufacture of alloys. Tin enters into combination with a large number of useful metals forming alloys of commercial significance. With lead, tin will mix in all proportions. The alloys are white and melt at a temperature below the melting-point of tin. One of the most important of these is known as solder which consists of varying proportions of tin and lead. Common solder consists of 1 part of tin and one of lead. Coarse solder of 1 part of tin and two of lead. Fine solder consists of 2 parts of tin and one of lead.

The old pewter ware which has become so highly prized for decorative effect in many dining rooms consists of 3 parts of tin and one of lead. The old britannia ware consists of 84 parts of tin, 10 parts of antimony, 4 parts of copper, and 2 parts of bismuth. Bell metal consists of 20 parts of tin and 80 parts of copper.

Tin is a constituent of a few brasses of importance, but, strictly speaking, brass is an alloy of copper and zinc. Tin is a necessary constituent of all bronzes. Many of these are capable of wide industrial application. It is also a requisite constituent in speculum metal. It is used in the manufacture of naval condensers. It is found also in many forms of babbitt. The true babbitts carry more then 50 per cent. of tin. They are known as friction-bearing alloys.

Tin unites with mercury in the formation of an amalgam used extensively in the filling of teeth, and when amalgamating anew with silver as a cement in joining the teeth together. Tin does not readily alloy with zinc alone.

Tin is used also in the detection of gold. A solution of stannous chloride in the presence of stannic chloride or free chlorine is one of the most delicate tests known for the yellow metal. The compound formed whose composition has been somewhat of an open question is known as the purple of Cassius.

An interesting point appears concerning the effect of tin on canned goods. According to F. Wirthle, who examined a large number of samples of canned beef, the white crust sometimes formed within the can was a basic tin chloride resulting from the action of the salt on the tin surface either by the direct action of the tin or by freeing first some organic salts of the tin, which was subsequently converted into a basic sodium stannous chloride and some organic sodium salt. From a large number of determinations the maximum of tin obtained was 0.014 per cent. in a can of beef that was five years old. The interior of the can was corroded in all cases where tin was in contact with fat, and not in a single instance had corrosion begun where tin was in contact with gelatin. The test employed in the detection of the tin was a solution of stannous chloride and ammonium molybdate. The test is delicate to 21–5,000,000 part of tin in solution. Even with this extreme dilution a beautiful blue coloration is observed.

There have been three sudden advances in the production and consumption of tin. The first came in the fourteenth century, which was marked by the use of tin for bell metal. The second came in the eighteenth century which was marked by the large use of tin in bronze for artillery. The third comes in the twentieth century which is marked by a large consumption of tin in canned provisions.

Tin is also utilized in the manufacture of tin foil for wrapping many small articles of commerce. The foil consists of a very thin sheet of lead coated with a thin film of tin. Tin is also used in silvering mirrors when amalgamated with mercury. The chloride of tin is used in dying and printing. The artificial oxide of tin under the name of putty powder is used in polishing granite. The polish thus obtained is far more lasting than that produced by oxalic acid.

During the last few years the separation of tin from tin plates,

scrap tin, type metal, babbitt, friction-bearing metals, tin cans, etc., has been carried on by the Vulcan Metal Refining Company of Sewaren, New Jersey. The method of extraction is by electrolysis. Fifteen per cent. of tin is said to be recovered from the old scrap tinware at a very low expense. The residue of steel is compressed into blocks by hydraulic pressure and sold to the open-hearth steel manufacturers for the same price as scrap tin (therefore the source of the tinware costs nothing save transportation).

Several companies have been organized in the United States for the purpose of exploiting tin deposits and the extraction of the metal from the ores obtained. The Niagara Tin Smelting Company, located at Niagara Falls, N. Y., and the North American Smelting Company of North Dakota. These companies have exploited the stream deposits in the Dakota tin belt and sought to enter actively into the production of tin. The American Tin Mining Company has produced a few tons of placer tin from Buck Creek in the Seward Peninsula. The Bartels Tin Mining Company in 1903 at Tin City, 5 miles southeast of Cape Prince of Wales, sunk several shafts and drove many drifts in their quest for tin, but the results were meager. The United States-Alaska Tin Mining Company has continued prospecting by tunnelling to a vein in Cape Mountain, but no production has resulted from their labors. The Tinton Company, South Dakota, has remodeled its mill and expects not only to mine tin but reduce the ores to the elemental state.

With an annual importation of tin valued at approximately $25,000,000 it appears as though the active exploitation of the tin placers and lodes deposits in the possible tin-bearing belts of the Carolinas, the Black Hills, and Alaska should be reasonably rewarded for the expenditure of time and money.

CHAPTER VII

USEFUL METALS CONTINUED (GROUP III)

IRON, ALUMINUM, CHROMIUM

Iron: Its Properties, Occurrence and Uses

Properties.—Iron, symbol Fe, is a lustrous white metal susceptible of a high polish. Native iron varies in color from steel gray to iron black. Iron is strongly magnetic but loses this property when highly heated. It is malleable and sectile. It does not oxidize in dry air but in the presence of moist air containing carbon dioxide it becomes coated with rust. The oxidation is far more rapid after the film of the oxide has once formed over the metal. Iron is soluble in the dilute mineral acids. The metal crystallizes in the isometric system. The specific gravity of native iron is 7.5, while that of the furnace product is 8.1. Its melting point is between 1550° and 1600° C. Its atomic weight is 55.85.

Minerals and Ores.—Next to aluminum, iron is the most abundant of all the metals. The principal iron minerals are as follows:

Native iron, Fe, 100 per cent. Fe. Often alloyed with cobalt, nickel and copper.

Pyrite, FeS_2, 46.6 per cent. Fe. Commonly known as fools gold, crystallizes in cubes, octahedrons and pyritohedrons.

Marcasite, FeS_2, 46.6 per cent. Fe. Occurs in orthorhombic crystals radiating from a common center and in an aggregation of crystals flattened into a crest-like form called cocks-comb pyrite.

Pyrrhotite, Fe_nS_{n+1}. With plus or minus 61.6 per cent. Fe. Commonly known as magnetic pyrite.

Melanterite, $FeSO_4{,}7H_2O$. A natural green vitriol.

Coquimbite, $Fe_2(SO_4)_3{,}9H_2O$. A ferric sulphate of some commercial significance in Chili.

Siderite, $FeCO_3$, 48.2 per cent. Fe. Often in rhombohedrons with curved faces.

Magnetite, Fe_3O_4, 72.4 per cent. Fe. The only iron-black mineral strongly magnetic before heating.

Franklinite, $(Fe,Mn,Zn)O,(Fe,Mn)_2O_3$, 44.1 per cent. Fe. Occurring in black octahedrons which vary in the degree of magnetism and in the per cent. of iron with the amount of manganese and zinc present.

Hematite, Fe_2O_3, 70 per cent. Fe. The only mineral with cherry red or blood red streak. It includes the specular iron ore, the Clinton ore, and the fossil ore.

Göthite, Fe_2O_3,H_2O, 62.9 per cent. Fe.

Xanthosiderite, $Fe_2O_3,2H_2O$, 57.1 per cent. Fe.

Turgite, $2Fe_2O_3,H_2O$, 66.2 per cent. Fe.

Limonite, $2Fe_2O_3$, $3H_2O$, 59.8 per cent. Fe.

Of the last species named only one of them appears crystallized and that is göthite. They are all classified in the trade as limonite and their fine powders vary in color from reddish-brown to yellow. The last named mineral, limonite, occurs in compact forms, sometimes in a pulverulent state, sometimes in stalactitic forms, in bog ores, and as brown clay-iron stone.

There are also many arsenides, arsenates, chromates, tungstates, columbates, niobates, etc., of iron but these are not of sufficient importance as a source of iron to be considered here. In fact, the minerals of which iron is an essential constituent are numbered by the hundreds.

The iron minerals of economic significance fall distinctly into four classes:

(1) Those used for the extraction of the metal. These in the order of their importance in America are, hematite, limonite, magnetite, and siderite. The production of each in 1905 was hematite 86.6; limonite 8.8; magnetite 4.5, and siderite 0.12 per cent. of the total. In England siderite is said to furnish more than 50 per cent. of the pig iron of Great Britain.

(2) Those used in their natural state as pigments after reduction to impalpable powders; hematite, limonite, and to a limited extent franklinite.

(3) Those used for the extraction of an acid radicle. For the extraction of sulphur are: pyrite, marcasite, and pyrrhotite. For arsenic of commerce: löllingite, $FeAs_2$, leucopyrite, Fe_3As_4, and arsenopyrite, $FeAsS$. For the extraction of chromic acid: chromite, FeO,Cr_2O_3. For the extraction of tungstic acid: wolframite, $(Fe,Mn)WO_4$. For the extraction of titanic acid:

ilmenite, FeO,TiO_2. The last three are used in the manufacture of chrome steel, tungsten steel and titanium steel.

(4) Those used in the extraction of an included metal. For gold and silver; pyrite, marcasite, and pyrrhotite. For nickel; pyrrhotite. Practically all the nickel for domestic consumption in the United States comes from the nickel-bearing pyrrhotite deposits of Sudbury, Ontario, a few tons of nickel only being produced at Mine La Motte, Missouri.

The sulphides, arsenides, and phosphates of iron play no part in the metallurgy of the metal in America because of the deleterious effect of each upon the resulting steel. The supply of the metal comes therefore from the oxides, the hydrous oxides and the carbonate.

Origin of The Ores or Minerals.—Native iron is quite widely distributed as a primary mineral in the basic intrusives as diabase and dolerite. T. Andrews reports native iron in the basalts of Ireland. F. Navarro found the metal in the basalts of Gerona, Spain. F. F. Hornstein reports native iron in the basalts near Cassel, Germany. C. H. Cook found native iron in the trap rocks of New Jersey. According to G. W. Hawes, native iron occurs in the dolerites of Dry River in the vicinity of Mount Washington. The iron is enclosed in grains of magnetite which may have been derived as a secondary mineral from the native iron. According to E. Hussak, native iron exists in the Auriferous gravels of Brazil. A. Daubreé and E. Meunier have reported the metal from the gold washings in the Urals. These placers contained traces of platinum but no nickel.

The largest and the most important body of native iron ever reported was discovered by A. E. Nordenskiold in 1870 at Ovifak, Disco Island, on the western coast of Greenland. Large masses or iron, sometimes weighing 20 tons, are encased in the basalt or weathered out in boulder-like or lenticular forms. It was first reported to be of meteoric origin. Lieutenant Peary brought some of these boulder-like masses of iron to the United States, and they have since been proven to be of terrestrial origin.

According to F. W. Clarke, they closely resemble meteoric iron, for they responded to Widmannstatten figures when etched, contained the rare mineral lawrenceite, which is a hydrous ferrous chloride, and was associated with magnetic pyrite and graphite. Another proof of its terrestrial origin is the absence of schreibersite, the phosphide of iron, which is common in meteorites.

Strensthrup found native iron disseminated in large bodies of basalt *in situ*, and considered it a part of the rock itself. Two questions have arisen concerning its origin: (1) Was it present in the original magma as metallic iron? (2) Was it reduced by carbonaceous matter in its upward transition through the earths crust?

F. W. Clarke states that the iron may have come as such from great depths below the surface to teach us that the earth is essentially a vast meteorite and that its interior is rich in uncombined metals.

According to A. Daubrée the latter supposition is admissable for he prepared artificially pellets of metallic iron containing nickel almost identical in composition with the specimens of native iron from Disco Island, Greenland.

According to C. A. Young, from 20,000,000 to 24,000,000 meteorites fall through the atmosphere of the earth every 24 hours. These particles blacken the snow and the ice of the permanent snow fields, sink to the bottom of the ocean, or mingle with the soil of the locality in which they happen to reach the earth.

Troilite, the ferrous sulphide, FeS, is common in iron meteorites in nodules disseminated more or less sparingly through the mass. It also occurs in narrow veins usually separated from the iron by a thin layer of graphite.

Pyrite and pyrrhotite occur as primary minerals as minor accessories in the igneous rocks. The former appears in both the acid and the basic intrusives, while pyrrhotite is more characteristic of the ferromagnesian varieties, as diabase and diorite. They have both been observed as sublimation products from volcanoes.

According to F. W. Clarke, dry gases, wet gases, and alkaline solutions charged with hydrogen sulphide are capable of producing these minerals. The magmas contain the reagents and the reactions naturally follow.

According to J. H. L. Vogt, these sulphides are actually soluble in silicate magmas, especially at high temperatures, and are among the first minerals to crystallize. Vogt regards certain of the pyrrhotite deposits of Norway as the direct product of magmatic segregation.

Marcasite, the orthorhombic sulphide, FeS_2, is common in metalliferous veins and in the sedimentary rocks, but its origin is unknown.

The nickeliferous pyrrhotite of Sudbury, Ontario, is by some authorities considered to represent a magmatic segregation. This origin has been advocated by A. P. Coleman and others, but the more recent investigations of W. Campbell have shown that the ores were deposited from circulating solutions and therefore of secondary origin. The hydrous sulphates of iron are always of secondary origin and of minor commercial significance.

Magnetite is often a primary mineral, solidifying along with chromite as the first segregations of a periodotite magma. This origin holds especially true for the magnetites and chromates of northern Vermont and Megantic County, Quebec. Magnetite is often a product of contact metamorphism. According to C. R. Van Hise, magnetite may be derived from marcasite and pyrite or even from the oxidation of siderite *in situ*. The mineral occurs as an accessory constituent in the rocks of all classes, but it is obviously more abundant in the rocks rich in the ferromagnesian minerals, as the diabases and the peridotites. In the Lake Superior region and in Michigan, Minnesota and Wisconsin, magnetite is found in the slates and cherts where the mineral is not of igneous origin.

According to C. K. Leith, the hematite of the Mesabi iron district has been leached from a hydrous iron silicate, greenalite, as FeO and developed magnetite where oxidation was partial. Other silicates through metamorphism may yield magnetite.

The carbonate, siderite, is always of secondary origin. It may be found in the igneous rocks as an alteration product. Carbonated waters can extract iron from silicate rocks or disseminated hematite and deposit their load, in the presence of much carbonic acid or decaying organic matter, as siderite. If the air has free access to these ferriferous waters the hydrated oxide, limonite, would be produced. If the waters are muddy the silt goes down with the iron compounds and the clay ironstones are the result. The black band ores of the coal measures were once a carbonaceous mud. In the presence of reducing agents as organic matter the carbonate will remain as such, but in their absence it will be oxidized and limonite may be the resulting product,

According to F. W. Clarke, hematite can crystallize out from a magma when the ferrous compounds are either absent or present in quite subordinate amounts, for the ferrous oxide unites with it to form magnetite. Hematite is therefore more common in the acidic than in the basic rocks. It is found as a pyrogenic

mineral in the crystalline schists but magnetite is far more abundant. According to C. H. Smyth, Jr., the oölitic hematite consists of concentric layers of hematite deposited around grains of quartz. The ore was formed in the shoal waters of a Silurian sea, presumably upon a sandy bottom. The iron was dissolved from ferruginous rocks and precipitated from solution by organic matter, or by oxidation, or by the carbonate of lime. The Clinton ores may be regarded as representing a contemporaneous metasomatic deposit in which the ore was formed during or immediately after the deposition of the original rock.

Hematite also occurs as a subsequent metasomatic ore body. Here the replacement took place some time after the deposition and consolidation of the original rock. The ferric sulphate traversing limestones may have the iron thrown out of solution by the action of calcium carbonate as hematite, and this mineral will then be deposited along the walls of a fault, or the joint plains of the limestones, or at the junction of two different terranes possessing different possibilities for the migration of solutions.

Such ore bodies are widely distributed and often associated with limestones.

There are five hydrous oxides of iron grouped together in this discussion under the name of limonite, because from a commercial standpoint all hydrous oxides of iron giving a brown, yellowish-brown, or reddish-brown streak are classified in the trade as limonite. Limonite is far the most abundant mineral of the group and forms large ore bodies. The five hydrous oxides are göthite, Fe_2O_3, H_2O; xanthosiderite, $Fe_2O_3, 2H_2O$; (limnite, $Fe_2O_3, 3H_2O$); turgite, $2Fe_2O_3,H_2O$; limonite, $2Fe_2O_3,3H_2O$.

Göthite is the only mineral in the group that is crystalline. The others are amorphous, and all sorts of admixtures between them may occur. The impurities often found in these ores afford some clue as to origin. They comprise sand, clay, organic matter, the carbonates of iron, calcium and magnesium, the hydroxides of aluminum and manganese, and the phosphate of iron, vivianite.

Limonite may result from the hydration of hematite. The decomposition of ferruginous rocks *in situ* yield laterite which here contains a mixture of the iron and aluminum hydroxides. The limonitization of pyrite or chalcopyrite is manifested in the gossan caps often reaching to a considerable depth. Waters charged with

carbon dioxide serve as a solvent for the iron in both the igneous and the sedimentary rocks and from these solutions limonite may be deposited. According to F. W. Clarke, organic acids and humus assist in the solution of ferrous compounds and furnish to swamp waters the material from which bog iron ores are formed. The atmospheric oxidation of siderite affords the irridescent films of ferric hydroxide so often seen on the surface of stagnant swamp waters.

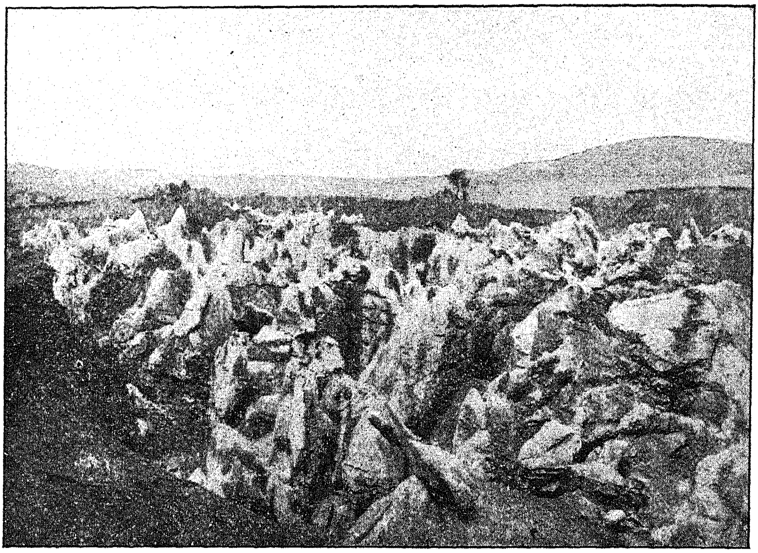


FIG. 102.—Old limonite pit, Ivanhoe, Virginia, showing pinnacled surface of limestone which overlies the ore-bearing clay. The level surface before mining began is seen on either side of excavation. (*By permission of the Macmillan Company, from Ries' Economic Geology.*)

According to N. S. Shaler, bog iron ores are far more abundant around the margin of swamps and often wanting at the centers. The deposition of the ore is not always as slow a process as is sometimes supposed. A. Geikie cites the accumulation of such ores to a thickness of several inches in 26 years in some of the Swedish lakes. The oxidation of ferrous sulphate solutions may also yield limonite. Acorcding to R. A. F. Penrose, limonite may be derived from glauconite through some process of alteration. It may form a replacement deposit in limestones, and even ferriferous limestones themselves may yield residuary limonite. (See Fig. 102.)

Character of the Ore Bodies.—The sulphides of iron, pyrite and pyrrhotite, occur in well-defined fissure veins, as primary segregations from a sulphidic magma, as contact deposits between igneous and sedimentary rocks. As stated earlier, the sulphides of iron play no part in the metallurgy of the metal in the United States. Attempts have been made in the southern Appalachian belt to manufacture high-grade pig iron from sulphides but these efforts proved futile and the process was abandoned.

Magnetite occurs (1) as lens-shaped masses differentiating from a peridotite magma (see Fig. 103); (2) as lenticular masses in the metamorphic rocks, this is by far the most important form of the ore bodies of magnetite of commercial significance; (3) as contact

FIG. 103.—Vein of norite, 30 to 70 yd. in width with schlieren of titaniferous iron ore. (*After J. H. L. Vogt.*)

deposits between intrusives and sedimentaries, but often too high in titanium to be of great commercial value; (4) as placer sands arising from the decomposition of the higher rocks, often auriferous, and (5) as beach sands on the shores of lakes and seas.

Hematite occurs as basin-shaped replacement deposits; as bedded deposits and as contact deposits. Limonite is often residuary. If fills the cracks, joint planes and fissures in the earlier stages of the decomposition of ferriferous rocks. It occurs also as replacement deposits. These are often concentrated into beds of great thickness. In the weathering of pyritiferous ore bodies and the leaching of chalcopyrite, limonite may be formed in sufficient quantities to be of commercial significance

as in the "Great Gosson Lead" in Virginia, and Ducktown, Tennessee.

Siderite occurs in bedded deposits in the Carboniferous terranes of western Pennyslvania and in several other localities along the Appalachian belt. It occurs in a clay bed lying beneath the Tertiary formations on the west side of Chesapeake bay for a distance of 50 miles. Siderite often constitutes a large part of the clay-iron stones of the Coal Measures and many shaly stratified deposits.

The impurities present in iron-ore bodies fall into two classes: (1) Those that are not seriously objectionable in small quantities save as they lower the iron content of the ore and thereby depreciate the ore in value. Calcium carbonate is often present in hematites that occur in bedded deposits between sandstones and limestones. If the lime content is high the carbon dioxide must be volatilized before smelting the ore. Clayey matter is often present in limonites as admixed material that requires a larger percentage of flux in the treatment of the ore.

(2) Impurities that tend to weaken the iron and therefore lessen its value. Silica is undesirable in iron ores for two reasons. It lowers the iron content of the ore and requires a larger amount of fluxing materials in its treatment. However foundry iron sometimes carries 10 per cent. or more of silicon. Sulphur is objectionable because of the brittleness imparted to the resulting iron. It is found as pyrite in the magnetites but it may arise from the presence of gypsum or barite in the limonites. Phosphorus is objectionable for the same reason. It is present in the mineral apatite associated with some magnetites. It should not be present in any iron ore in excess of one-tenth of 1 per cent. It cannot be volatilized in either the blast-furnace or the acid converter used in the manufacture of Bessemer steel, and therefore it appears in the finished product. Titanium is a common injurious constituent found in many magnetites. It does not render steel brittle but it renders the ore highly refractory and forces a part of the iron into the slag. In the manufacture of titanium steel the metal should be added directly as an alloy.

Geographical Distribution.—There are three distinct belts of iron ores in the United States. (See Fig. 104.)

(1) The Appalachian district; (2) the Lake Superior district; and (3) the Cordilleran section.

Until recently practically all of the iron ores of the United

States came from the eastern side of an imaginary line drawn from Lake Winnepeg on the north to the eastern base of the Rockies, thence southward to the Rio Grande River. It will be remembered that practically all of the gold in the United States comes from the western side of the same line.

(1) *The Appalachian district* stretches in a northeasterly direction from Alabama on the south to Newfoundland on the north, and may itself be subdivided into three distinct fields, especially with respect to age and the character of the ores involved. (1) The pre-Cambrian belt where the ores are largely magnetites and specular hematites. These are especially

Fig. 104.—Map showing distribution of hematite and magnetite deposits in the United States. After Harder. (*By permission of the Macmillan Company, from Ries' Economic Geology.*)

abundant in the Adirondack region, southeastern New York, northern New Jersey, southeastern Pennsylvania and in Tennessee. (2) The Cambro-Ordovician ores, hematite and limonite, are distributed along the great Appalachian valley, and even abundantly in western New England. (3) The Clinton ore, fossiliferous or oölitic, of Silurian age. These deposits are especially well developed in central New York, where they were first discovered at Clinton, Oneida County, N. Y., and in Alabama.

The terranes of the Adirondack region are almost exclusively pre-Cambrian. The exceptions are the occasional inliers of

Potsdam sandstone of Cambrian age, deposited unconformably upon the older formations.

According to J. M. Clarke the metamorphic series consists of the Grenville series of limestones and dolomites, gneisses of both acidic and basic character bearing the common metamorphic silicates together with graphite and pyrite; amphibolites composed mostly of hornblende; quartzites and gneisses. The igneous rocks consist of anorthosites, gabbros, syenites, granites, with later diabase dikes.

The normal magnetites occur both upon the eastern and the western side of the Adirondack Mountains. One of the most productive localities is Mineville, which is situated to the northwest of Port Henry. The ores are granular masses of magnetite, lenticular in character, but often in so nearly a horizontal position, and of such length that they appear like bedded ores. According to Kemp and Newland these magnetites are differentiation products. Newland substantiates this theory by noting, in the acid intrusives of the area involved, a large excess of iron above the percentages required with the lime and magnesia in the formation of silicates.

The titaniferous magnetites of New York are found chiefly in Essex and Franklin counties. The ore bodies occur in the intrusive anorthosites which are traversed by dikes of gabbro. Small ore bodies are found within the gabbro, in tabular form and conformable with the strike of the dikes. The larger ore bodies in the anorthosites may represent differentiation products formed during the solidification of the anorthosite magma, or they may represent intrusives forced into the anorthosite after a partial solidification of the anorthosite magma had taken place. The ores bear both titaniferous magnetite and ilmenite, FeO, TiO_2. The gangue minerals associated with the ores are the amphiboles, the pyroxenes, olivine, and the metamorphic minerals spinel and garnet.

The Cambro-Ordovician belt finds its best representative at Cornwall, Pennsylvania (see Fig. 104). The ore bodies of magnetite form large and small masses of somewhat irregular shape, either within the sediments themselves, or at their contact with intrusive Triassic diabase. While the ores appear as contact deposits the characteristic silicates of contact metamorphic deposits are largely wanting (Fig. 105).

One of the best magnetite beds in northern Vermont is found

in Troy about two miles northeast of the village bearing that name. Three veins of the ore were worked about the middle of the nineteenth century and the resulting iron used only locally on account of the great distance from the railroad. A portion of this ore was worked in a foundry on the banks of the Missisquoi river near the ore deposit, while a part was shipped to St. Johnsbury, 50 miles distant. The freedom from sulphur and phosphorus of this ore made it especially desirable for all purposes where an extremely tough steel was sought. The ore bodies

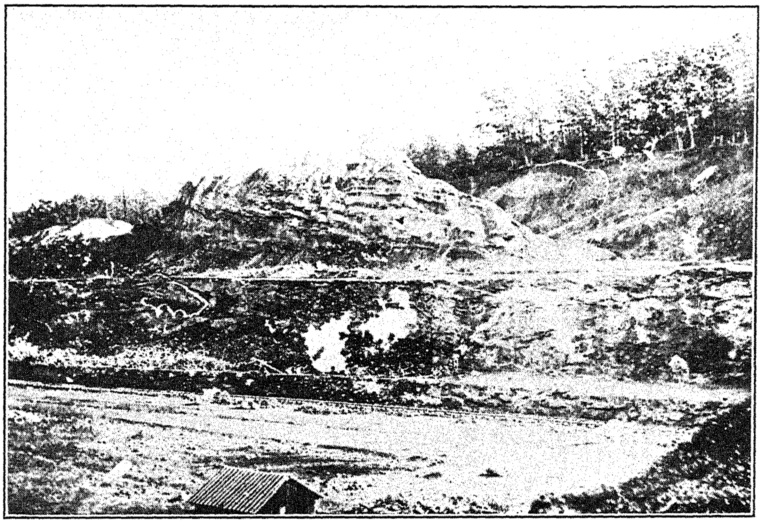


FIG. 105.—Magnetite mine, Cornwall, Pennsylvania, showing structure of the ore. (*Photograph by T. C. Hopkins.*)

represent primary segregations in a peridotite magma in Cambrian terranes. They are not worked at present.

In the northward extension of this belt into Canada large lenses of magnetite are encountered in Megantic County, Quebec. These ore bodies are more or less lens-shaped and occur near the outer margins of the peridotite or even within the peridotite itself. The ores represent differentiation products in the peridotite magma. The mines are still prominent producers.

The third division of the Appalachian belt is widely known as the Clinton ore of Silurian age. These ores are sometimes called fossil ore, pea ore and dyestone ore, but the term Clinton

ore is in far more general use. The ores are found in many localities from Alabama to Newfoundland, where the Clinton terrane is represented. The ore bodies are interstratified with shales and sandstones and occur as beds or lenses of varying length and thickness. Sometimes two beds will be represented in the same locality, and in some cases three or even four beds may be encountered. In thickness the beds vary from a few inches to 10 ft. In some instances where the ore bodies are more lens-shaped they reach a thickness approximating 40 ft.

In central New York as well as in Newfoundland the beds are nearly horizontal, while in the Appalachian region the dip at times becomes quite high. Two varieties based upon texture are well known. (1) The fossil ore which consists largely of fossil fragments. (2) The oölitic ore which consists of grains of silica encircled by hematite. The ores at the surface are low in their lime content from the solution of the associated carbonate, and soft as a result of weathering agencies, while the lower portions of the ore body are higher in lime and hard because the calcium carbonate with which the ores are associated has not been removed.

At Birmingham, Alabama, the Clinton ores are of great commercial significance. The ore beds are situated on Red Mountain, associated with sandstones and shales, and reach a maximum dip of 50 degrees to the west. The burden of the overlying material is often light and the ore is mined by open-cut method and by stopes. The peculiar significance of the field lies in the fact that to the west of the ore there is an abundance of Cambrian limestone for a flux, and to the east two coal basins for fuel. Thus all the essentials of a successful pig-iron industry exist at Birmingham: (1) Iron ore for the extraction of the metal; (2) limestone in close proximity for flux; and (3) coal in abundance for fuel.

According to H. Ries the more important Clinton iron-ore deposits may be classified as follows: (1) West Central New York. (2) Several narrow belts in central Pennsylvania. (3) Alleghany County, Virginia. (4)Lee and Wise Counties, Virginia, extending in a southwesterly direction into the La Follette district in Tennessee. (5) Narrow belts in the neighborhood of Chattanooga, Tennessee. (6) Birmingham, Alabama. (7) Bath County, Kentucky. (8) Dodge County, Wisconsin. (9) Newly discovered ores in Missouri. (10) Belle Isle, Newfoundland.

Three important theories have been advanced to account for the origin of these ores.

(1) Sedimentary origin. James Hall, C. H. Smyth, Jr., and S. W. McCallie have advocated that the ores are of contemporaneous origin with the inclosing rocks and that they have been deposited upon the Silurian sea floor as chemical precipitates. Hall believed that the essential iron of the present ore was leached out of the older crystalline rocks and deposited as a chemical precipitate. Smyth considers that this leached iron was transported from the associated crystalline areas into shallow basins in the Silurian sea and deposited around sand grains or any nuclei that were available. McCallie believes that the original iron mineral was either glauconite or greenalite. The continuation of the ores with depth, as in Alabama where the ores are encountered 800 ft. below the surface, and in Missouri where the ores have been encountered by drillings, is an additional proof of the sedimentary origin of these ores.

(2) Residual Enrichment. I. C. Russell advocated the theory that the Clinton iron ores were derived from ferruginous limestones by weathering agencies. The iron representing the less soluble portions of the formations would remain in a more concentrated form due to the loss of the limestone through solution and transportation. Russell cites a 57 per cent. iron content at the surface of the Clinton limestone near Attalla, Alabama, and an iron content of only 7.75 per cent. at a depth of 250 ft. E. C. Eckel has pointed out that at a depth of 250 ft. the iron content sometimes rises as high as 42 per cent., therefore the validity of the theory is called into question.

3. Metasomatic Replacement Deposits. According to J. J. Rutledge the ores are of much later origin than the associated terranes. He believes that the iron content of the overlying shales was leached out by weathering processes and deposited as a metasomatic replacement of calcium carbonate by the anhydrous iron oxide. He cites in substantiation of his theory the following arguments: (1) The invariable association of the soft rich ore with leached decolorized shales together with the association of the hard lean ores with bright unweathered shales. (2) The relation of the ores with the shattered sandstones and to the topographic situation of the ores. (3) The fact that analogous replacements are in the process of formation at the present time in the Medina sandstone. (4) The progressive downward

transition of the associated limestones to iron ores traceable both in the field and in the chemical laboratory. (5) The absence of crumpling and shrinking of the strata, which points to a relative rather than an absolute enrichment of the ores (Fig. 106).

There are many widely scattered occurrences of limonite along the Appalachian belt. These are especially abundant in Alabama, Georgia, Tennessee, Virginia, Pennsylvania and Vermont. The ores are often of uncertain or variable composition on account of the admixed clayey matter, silica, and in some instances vegetable matter. Beds of bog iron ore or limonite have been worked near Brandon, Monkton and Bennington, Vermont, and in several other localities in the southern part of the state.

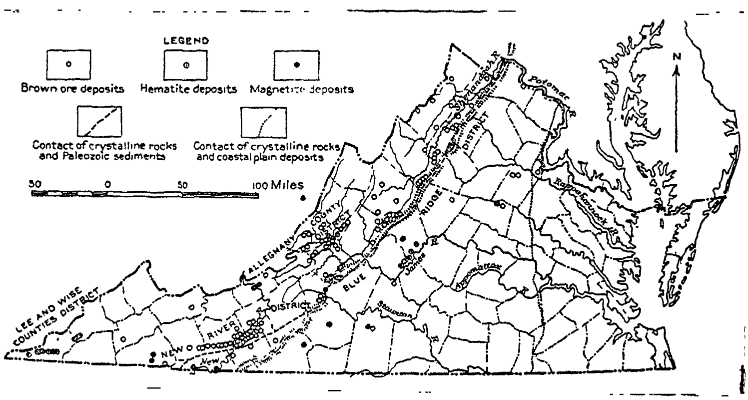


FIG. 106.—Map showing location of iron-ore deposits in Virginia. After Harder. (*By permission of the Macmillan Company, from Ries' Economic Geology.*)

They were at one time of considerable commercial significance. The iron ores of Brandon were discovered in 1810 and soon after that some iron of superior quality was manufactured for several years. The limonites of Alabama and Virginia furnish more than 50 per cent. of the hydrated iron oxides in the United States.

The more important limonites are residual deposits forming two distinct types of ore bodies.

Residual Limonites.—These result from the weathering of vast areas of ferruginous rocks and the deposits appear as masses in the residual clays. Limonites may also occur as bedded deposits, replacement deposits, and as bog ore deposits in swamps

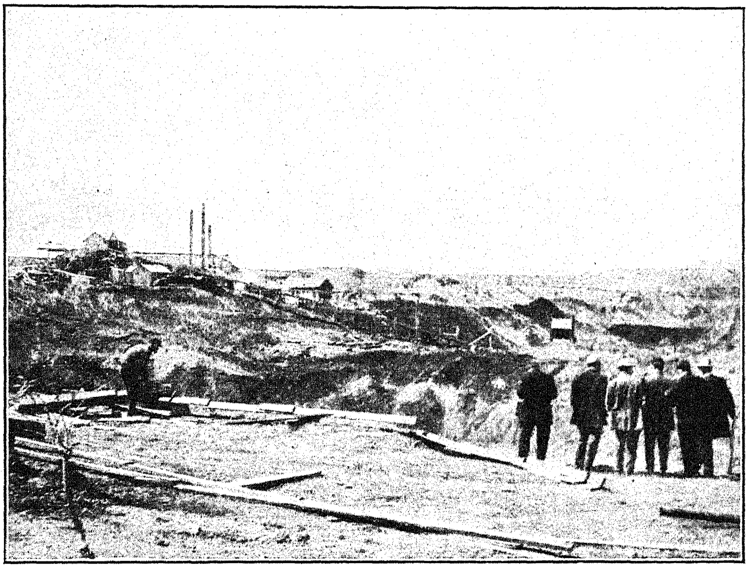


FIG. 107.—View of limonite pit near Ironton, Pennsylvania. (*By permission of the Macmillan Company, from Ries' Economic Geology.*)

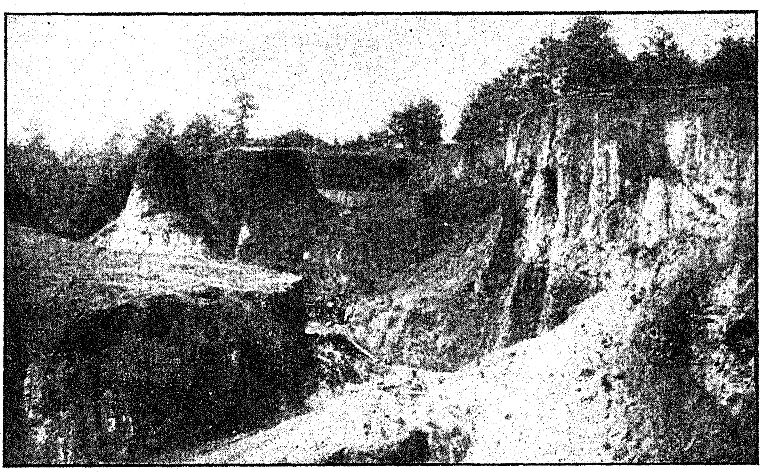


FIG. 108.—Pit of residual limonite, Shelby, Alabama. (*By permission of the Macmillan Company, from Ries' Economic Geology.*)

and bogs. The residual limonite ore bodies occur in many scattered localities both in the Blue Ridge and the Appalachian mountains either in the Cambrian quartzites at or near their contact with the overlying limestones or in the limestones themselves. The former are called mountain ores and the latter the valley ores (Fig. 107).

Gossan limonites. These are derived from the disintegration and oxidation of the sulphides of iron and copper where the more soluble constituents have been transferred downward for the enrichment of the underlying ore bodies or carried elsewhere in solution. The ore in such deposits sometimes contains 41 per cent. iron. Corinth and Vershire, Vermont; Cooper, Virginia; and Ducktown, Tennessee, represent such deposits (Fig. 108).

2. *Lake Superior District.*—This field is by far the most important iron-ore district of the world. It furnishes more than four-fifths of the iron ores of the United States and therefore more than four-fifths of the pig iron. The ores are mostly hematite, although there is some magnetite in the Marquette field in Michigan (Fig. 109).

The Lake Superior region may be further subdivided into seven districts each worthy of a detailed description: (1) Mesabi district in Minnesota; (2) Vermillion district in Minnesota; (3) Cuyuna district in Minnesota; (4) Marquette district in Michigan; (5) Crystal Falls district in Michigan; (6) Menominee district in Wisconsin; and (7) Penokee-Gogebic district on the Michigan and Wisconsin boundary.

1. Mesabi Range. The Mesabi iron range comprises by far the most important district in the Lake Superior region, and it produces more iron ore than all of the others combined.

According to C. K. Leith, the geological section comprises at its base Archean greenstones, hornblende schists and porphyries which are separated from the Lower Huronian terranes by an unconformity. The Huronian terranes comprise the equivalents of the Ogishke and Knife formations of the Vermillion district, slate-graywacke formations and conglomerates in nearly vertical position; and granite intrusives in the lower formations. These are separated from the Upper Huronian by another unconformity. The Upper Huronian terranes comprise the Biwabik iron formation, the Pokegama quartzite and quartz slate; and the Virginia slate. This slate is separated in turn from the

Keweenawan by another unconformity. The Keweenawan formations consist of gabbro and granite intrusives in all of the lower formations. All of the foregoing rocks are separated from the Cretaceous by another unconformity.

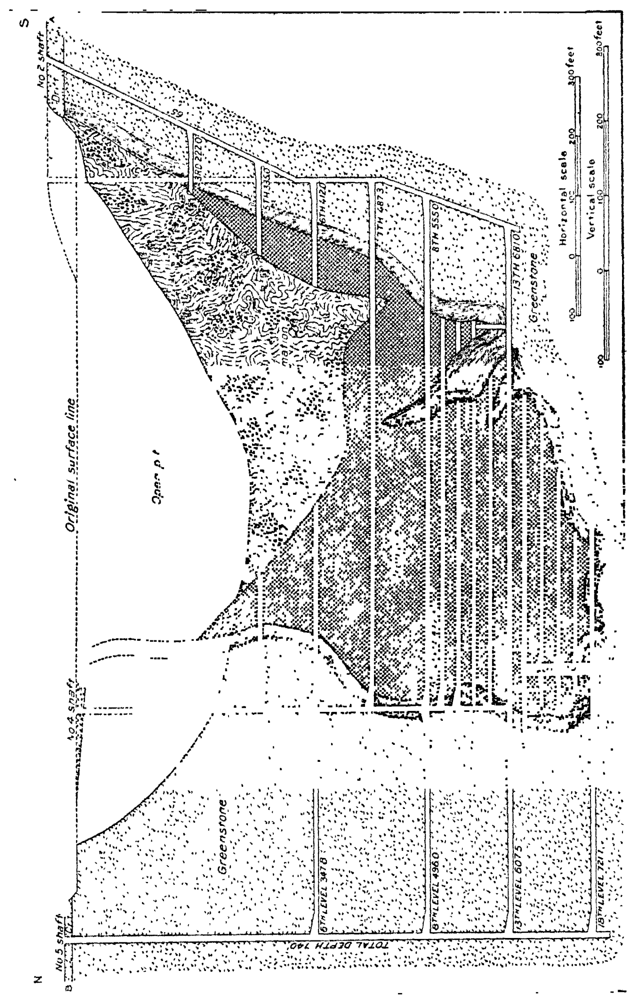


FIG. 109.—Vertical section through the chandler mine, Vermillion district. (*After J. M. Clements, U. S. Geological Survey.*)

The Biwabik iron formation forms a continuous belt from Grand Rapids on the west to Birch Lake on the east. Its breadth varies from a quarter of a mile to more than two miles. It presents four widely different varieties of ferriferous rocks. (1)

A lean ferruginous chert, the chert and iron occurring in alternate bands, or irregularly mixed. (2) Iron ore bodies. (3) Ferrous silicate and carbonate rocks. (4). Ferruginous slates.

The iron was originally present in part as a carbonate but mostly as the silicate, greenalite. Surface waters charged with carbon dioxide attacked the greenalite forming the carbonate of iron and orthosilicic acid. The iron carbonate was either taken into solution and precipitated by contact with solutions bearing an abundance of oxygen, or else it was oxidized and hydrated *in*

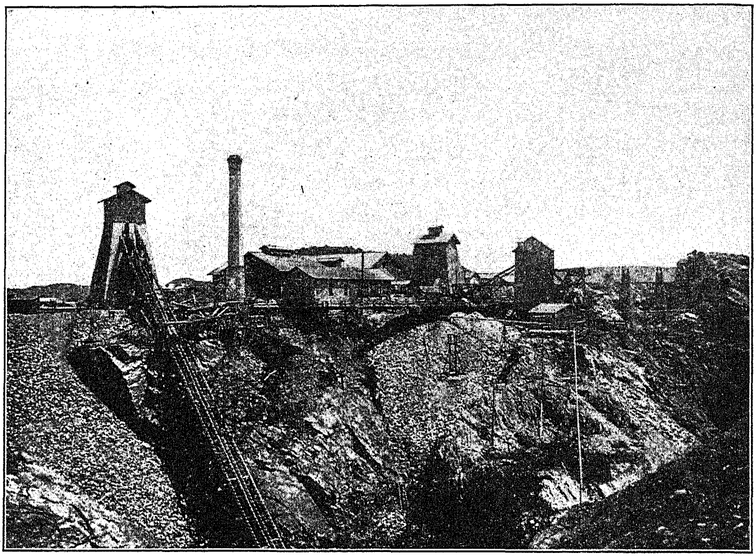


FIG. 110.—Iron mine, Soudan, Minnesota, shows old open pit with jasper horse in middle. (*By permission of the Macmillan Conpany, from Ries' Economic Geology.*)

situ. The removal of the orthosilicic acid in solution is cited as responsible for the slumping of the beds at the contact of the wall rock and the ore bodies.

2. The Vermillion District: According to J. M. Clements this district comprises a narrow belt of Archean rocks in places overlain by those of the Huronian series extending in a northeasterly direction from Vermillion Lake, Minnesota, to Gunflint Lake on the International Boundary, a distance of about 92 miles. The district is one of extremely complex folding. Superimposed upon the longitudinal folds are cross folds with steep

pitches which shows that the transverse folding was intense. The structure of the district is further complicated by intrusives of various ages. Unlike the other districts the iron ores occur in the Achean, Lower Huronian and Upper Huronian formations. It differs also in that the chief producer of iron ores is the Archean formation. The ores occur in the upper portion of the Archean terranes known as the Soudan iron formation. It consists of cherty iron carbonates, ferruginous cherts, pyritic quartz rocks, jaspilites and ore bodies. The ore bodies are usually near the base of the formation and occur in synclinal troughs in the greenstones. At Soudan the ore bodies are underlain in part by the greenstones and in part by the associated porphyries (Fig. 110).

The Lower Huronian iron-bearing terrane is known as the Agawa formation. The ores occur chiefly in the eastern part of the district on Hunter's Island, Canada. The formation consists of ferruginous cherts, ferruginous slates, jaspilites and iron-bearing carbonates.

The Upper Huronian iron-bearing terrane is known as the Gunflint formation. It is confined to the northeast part of the district west of Gunflint Lake. It consists of carbonaceous slates, ferruginous slates, and jaspilites, in the vicinity of Gunflint Lake, but to the southwest it passes into amphibolitic and magnetic quartz rock due to the metamorphism of the associated gabbros.

3. The Cuyuna District: This range is southwest of the Mesabi range in Minnesota. The formations include quartzites and their altered equivalents, iron formations, slates, together with intrusive granites and diorites. The ore occurs in lenses from 100 to 250 ft. in thickness.

4. The Marquette District: This district, according to C. R. Van Hise, W. S. Bayley and H. L. Smyth, comprises a comparatively small east and west belt situated wholly within the state of Michigan. The geological section comprises formations ranging from the Archean to the Cambrian. The iron-bearing formations occur in all four of the horizons at which iron ores are found in the Lake Superior region; viz., The Archean, the Negaunee formation of the Middle Huronian, and in two horizons in the Upper Huronian, the one at the base of the Goodrich quartzite and the other in the Bijiki-formation. Negaunee is the chief iron-producing district. It consists of cherty iron carbonates, ferruginous slates, ferruginous cherts, jaspilites, grünerite magnetite schists, detrital fragmental rocks and iron-ore bodies (Fig. 111).

According to Van Hise the orginal iron ore formation was a cherty iron-bearing carbonate which in some localities closely approached a siderite. The upper part of the Negaunee formation in Inter-Marquette times was transformed into ferruginous slates and ferruginous cherts. In the early Upper-Marquette time detrital material from the Negaunee formations accumulated. This material, formed at the base of the Upper-Marquette series, consisted of iron oxide and quartz. Thereafter the original rock masses, the weathered rocks *in situ,* and the detrital material were all buried beneath Upper-Marquette sediments and igneous rocks of Upper-Marquette and Keweenawan age.

While these rocks were deeply buried they were intensely folded. Where the original carbonate of iron remained and especially where it was intruded by abundant igneous rocks it was partly transformed into a grünerite magnetite schist. The iron

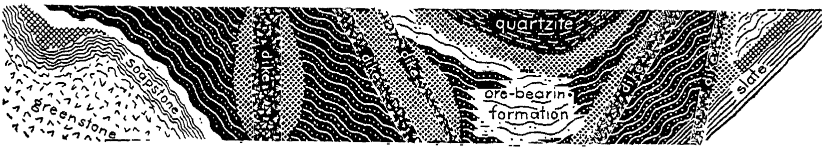


FIG. 111.—Generalized section in the Marquette district showing the relation of all classes of ore deposits to the associated formations. (*After C. R. Von Hise, U. S. Geological Survey.*)

oxide of the ferruginous slate and ferruginous cherts was dehydrated and these rocks were transformed to jaspilites. The detrital ores were converted into hematite and jasper quartzites and conglomerates. Subsequent to this period of folding, but prior to Cambrian time, the region was folded anew. Denudation cut through the Upper-Marquette formation and again exposed the Negaunee terranes to the processes of weathering. Where the unaltered cherty iron carbonate was abundant it was transformed into ferruginous slates and cherts. It was at this period of alteration that the ore deposits were developed.

According to E. T. Hancock the workable deposits of the Negaunee formation may be divided into three classes. (1) Ore deposits at the base of the iron-bearing formation. (2) Ore deposits within the iron-bearing formation. (3) Ore deposits at the top of the Negaunee formation and at the base of the Goodrich quartzite.

5. The Crystal Falls District: This district, according to J. M. Clements, H. L. Smyth, W. S. Bayley, and C. R. Van Hise, comprises a geological section extending from the Archean to the Cambrian. The ore bodies occur: (1) In the Mansfield slate where only one ore body of considerable dimensions has been worked. This varies from 16 to 32 ft. in thickness and stands in almost vertical position, (2) also in the Negaunee or Groveland iron formations where the ore bodies are comparatively small and the ore mainly a hard and siliceous hematite, and (3) within the Michigamme formation where the large deposits at Crystal Falls occur. The ore is chiefly a soft red hematite, though frequently hydrated and classified in the trade as brown hematite.

No. 1 is in the Lower Middle Huronian formations. No. 2 is in the Upper Middle Huronian formations. No. 3 is in the Upper Huronian formations.

6. The Menominee District. This district, according to C. R. Van Hise and W. S. Bayley, lies mostly in Wisconsin and the geological section extends from the Archean to the Ordovician. The ore bodies occur: (1) In the Traders ore-bearing member which is Middle Huronian. (2) In the Brier slate which is conformable with the Traders iron-ore-bearing member also of Middle Huronian age. (3) In the Curry ore-bearing member which lies conformably upon the Brier slate formation and of Middle Huronian age. Rare bodies of ferruginous slate and iron oxide occur in the Upper Huronian formations. The ores of the Menominee district are mainly gray, finely banded hematite with lesser amounts of a flinty hematite which shows local banding.

7. The Penokee-Gogebic District. According to R. D. Irving and C. R. Van Hise, this district comprises a narrow belt south of Lake Superior with strike north 70 degrees east. The most productive portion of the belt lies in Michigan and the remainder in Wisconsin. The geological formations are the Archean, Lower Huronian, Upper Huronian, Keweenawan and Cambrian. Each is separated from its successor by an unconformity. The ore bodies occur in the Upper Huronian terranes, which consist of a quartzitic slate and the Ironwood formation, above which is the Tyler slate. The ore bodies closely resemble those in the Mesabi district in that they occur between two slate belts.

Previous to the introduction of great masses of igneous rocks in Keweenawan times the original cherty iron carbonate was largely decomposed with the production of some magnetite, and

some actinolite, forming an actinolitic magnetite schist which meteoric waters were unable to transform into a productive ore body. The productive portion remained through this period as a slightly altered cherty iron carbonate. When in subsequent times the district was folded and erosion was carried to the extent that the iron-bearing formations were exposed to the action of meteoric waters, the siderite was altered to ferruginous slate, ferruginous chert and iron ores. A soft hydrated ferric oxide constitutes the main part of the ore. Hard slaty ore is not un-

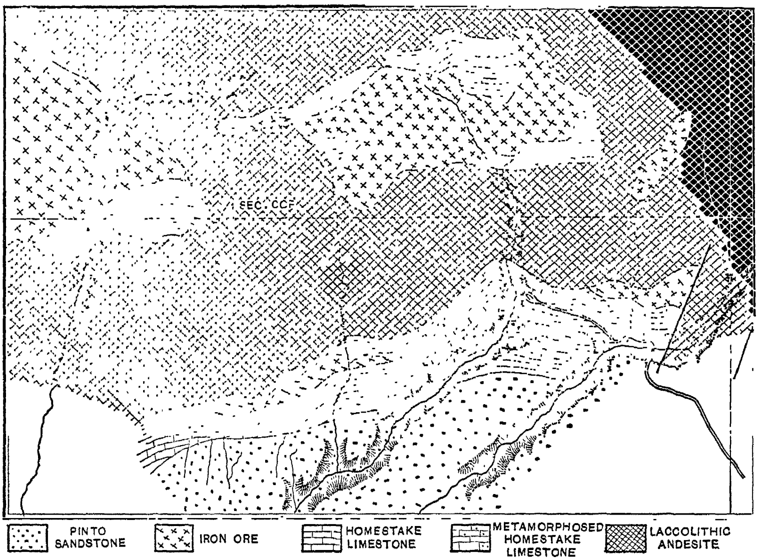


FIG. 112.—Map of a portion of the Iron Springs, Utah, district, showing occurrence of iron ore in limestone near andesite contact and also in the igneous rock. After Leith and Harder. (*By permission of the Macmillan Company, from Ries' Economic Geology.*)

common, and the oxides of manganese occur in a few deposits.

3. *The Cordilleran Section.*—There are many widely scattered occurrences of iron ores in the Cordilleran section. Many of these are not worked owing to the long distance from the railroad, or a limited demand for iron, or the character of the ores (Fig. 112).

In the southern part of Gunnison county, Colorado, there is a quantity of magnetite in the Cebolla district. According to J. T. Singewald, Jr., the ores occur (1) in the basic igneous rocks.

(2) in the basic igneous-limestone complex; (3) in the limestones themselves.

1. Ores in the Basic Igneous Rocks: The richer ores consist of aggregates of titaniferous magnetite and bunches of dark brown mica. In such ores the pyroxenes are not abundant, but the ores pass into leaner varieties in which the pyroxenes are abundant and finally into a rock consisting almost exclusively of pyroxene. There is little evidence of the occurrence of large ore bodies but rather of the occurrence of a large number of small ore segregations. The composition of the ores, their mineralogical association, and their manner of occurrence establishes beyond doubt their genetic position. They are magmatic segregations of titaniferous magnetites in a basic igneous rock.

2. Ores in the Basic Igneous-limestone Complex: The most interesting feature of this complex is the occurrence of small deposits of contact metamorphic ore. The metamorphic rock is made up of calcite, augite, garnet, and less abundantly, zoisite and vesuvianite. Within the contact metamorphic rock are numerous pockets and nests of magnet te. The ores consist of ilmenite and magnetite. The most important and striking feature of the district is the occurrence of highly titaniferous magnetite of contact metamorphic origin.

3. Ores in the Limestone: The limestone in this district, wherever exposed, has been more or less replaced by iron. On Iron Hill the ore is principally siderite and limonite. In the small hill to the north the resulting product is chiefly a yellow ferruginous jasper and a highly siliceous limonite. In some places the siderite has been changed to hematite, but the structure and cleavage of the siderite are still preserved.

An analysis of the ore cited in the same paper gives the iron protoxide as 8.46 per cent. and the iron peroxide as 69.04 per cent.

Hematite deposits also occur in Carbon and Laramie Counties, Wyoming, in the pre-Cambrian schists. Those in the Hartville district in the latter county are of the greatest commercial significance. The more important ore bodies occur as lenses in the schists with a foot wall of limestone. In some instances it fills the joint planes and breccia cavities. Two grades of ore are found in this district. One a hard hematite with about 60 per cent. iron content. The other is a soft, greasy, hydrated, reddish-brown ore. This ore has been derived from the hard variety by the action of waters.

According to Ball the ore was deposited by descending waters. It occurs along zones of maximum downward circulation. Lenses and veins are found along joints in the rock masses at a considerable distance from the main body. The associated minerals are quartz, calcite and limonite which have been deposited from solution. In this case the magnetite and the pyrite of the overlying schists would be the source from which the circulating solutions derived the iron.

In Iron Mountain, Wyoming, titaniferous magnetites are found in dikes traversing anorthosites. The mountain itself is more than a mile in length and the iron-bearing ridge is about 600 ft. in width. The ore which is in the form of a dike extends the length of the ridge and varies from 40 to 300 ft. in width. It is flanked upon either side by the anorthosite and paralleled by numerous smaller dikes. The presence of similar minerals in both the anorthosite and the dikes, although the proportions vary somewhat, suggests that they are differentiation products of the same magma with the iron intruded after the complete solidification of the anorthosite. The impurities in the dike material are olivine, biotite and feldspar. The percentage of iron is about 50. Lenticular masses of granite are also found associated with the anorthosite. The granite is also traversed by a pegmatite bearing magnetite and biotite. In order of age the intrusives of the district may be given as anorthosite, iron ores, granite, pegmatite.

Hanover, New Mexico: A comparatively new field for the production of iron ore is near Hanover, New Mexico. The geological relations are fairly simple. A quartz diorite porphyry has intruded Carboniferous limestones and other sedimentaries. In a part of the area the intrusion has caused extensive metamorphism of the terranes, and, along the contact zone, ores of iron, copper, and zinc have been deposited. The ore is primarily magnetite but in part it is hematite. The ores are both hard and soft. Of the former there are three large lenticular masses and numerous outcrops that appear to have the same mode of occurrence. The soft ores occur at several places along the contact between the igneous and sedimentary rocks. The ore content is estimated by Paige as between 53 and 57 per cent. Solutions from the heated magma, probably above the critical temperature, impregnated certain strata of the surrounding rocks. Adjustments due to cooling served to make the contact zone favorable

for superheated gases. Magnetite, which several investigators have shown might be precipitated from iron silicates by reaction with lime, replaced the limestone, and, in part, the porphyry mass.

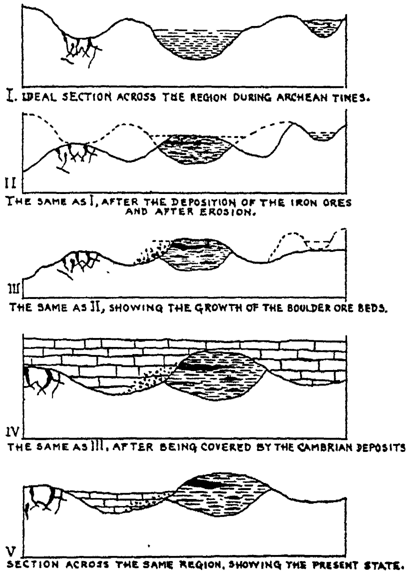


FIG. 113.—A group of ideal sections showing the probable history of the iron ores of Pilot Knob, Missouri. (*After Nason.*)

There are other occurrences of iron ores in the United States that are of commercial importance, as shown in Figs. 113 and 114.

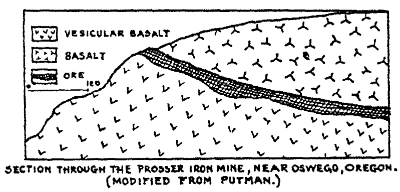


FIG. 114.—Section through the Prosser mine, near Oswego, Oregon. (*Modified from Putnam.*)

Numerous masses of igneous rocks belonging to the gabbro and norite families are found in the southern part of Norway and Sweden (see Fig. 115). In these masses are found some of the

most famous iron-ore deposits of the world. The iron ores occur partly as segregations in the norite dikes and partly as veins, or basic zones in the anorthosites.

According to Thomas and MacAllister the iron ores in the norite dikes at Storgangen consist of an intimate mixture of ilmenite and hypersthene, together with a little labradorite. The iron-ore deposits of Taberg, Sweden, are titaniferous and are rich in olivine rather than hypersthene. The Taberg ores and their associated gabbros are regarded as having their origin in the same igneous reservoir.

In the Ural Mountains there are several well known districts in which iron-ore deposits are associated with porphyritic rocks. The porphyries consist largely of orthoclase, plagioclase, augite, sometimes with the original augite metamorphosed into hornblende. The segregations from these masses are largely mag-

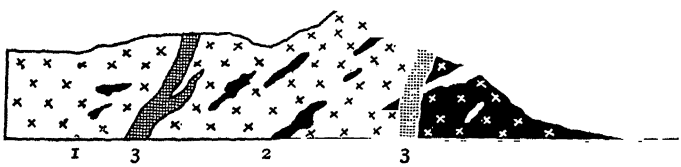


FIG. 115.—Section to illustrate the mode of occurrence of iron ores in the Ekersund—Soggendal district. (*After Thomas and MacAlister's Geology of Ore Deposits.*)

netites which occur as irregular patches and veins passing by insensible gradations into the country rock.

The iron ores of Lorraine and Luxemburg, Europe, have a variable composition. The ores exist as oxides, including magnetites, also as carbonate and silicate. The ores are due in a large measure to contemporaneous replacements and in part to original depositions.

The hematite deposits of southern Wales, Cumberland and Lancashire occur in the Carboniferous limestones and may be due to the leaching of iron compounds from the overlying Permian terranes and the subsequent deposition of the iron ores by metasomatic action.

The iron ores from the Island of Elba, often beautifully crystallized, have found their way into nearly all museums. Upon the island there are four distinct districts: Rialtaño, Rio, Terra-Nova and Calamita. Limonites and magnetites are present as well as

hematites. They occur as replacement deposits in limestones of Triassic age. Sometimes all traces of the original limestones have been removed and so complete has been the interchange of material that a fairly compact bed of ore rests directly upon the associated underlying Paleozoic rocks. It appears to be generally accepted that the replacement of the limestone was brought about by ferruginous solutions which found their way into the calcaeous rocks in post-Eocene times.

Geological Horizon.—Iron ores are comfined to no particular geological age. They are especially abundant in the pre-Cambrian, Cambrian, Ordovician, Silurian, Carboniferous and Tertiary ages. Bog iron ores are in the process of formation even at the present time.

Methods of Extraction.—At the Illinois Steel Works of South Chicago the ore used in the manufacture of pig iron comes from the Lake Superior district. The ore is removed from boats by means of electric cranes and transported either to the storage yards or to the furnaces for immediate treatment. The type of furnace used is known as the blast furnace. Each furnace shaped like an inverted bottle is about 80 ft. high and tapers more rapidly toward the base than toward the top. The upper part of the furnace into which the ore, coke and limestone are fed is called the throat. From the throat down to the widest part of the furnace it is called the stack. The lowest part is called the bosh. The part of the furnace on which the ore lies is called the hearth. Here is where the greatest heat is produced and where the ore is smelted. About 4 ft. above the hearth are the tuyeres through which a blast of air is introduced into the furnace. The blast is heated by the hot gases which are generated in the furnace. The zone of fusion is just above the place where the bosh joins the hearth. The fluid iron sinks to the bottom of the furnace while the resulting slag with its lighter specific gravity floats on the surface of the molten metal. The slag is drawn off into V-shaped troughs through which a stream of cold water is flowing. The slag is therefore shorted and transported to large cylindrical tanks from which it is subsequently removed and utilized in the manufacture of cement.

The molten metal is drawn off into ladles containing about 20 tons each or into sand troughs each containing about 300 lb. of the metal. These bars, not unlike cord wood in shape, are pig iron.

Bessemer steel is made by burning out the impurities of the iron by blowing air through the molten metal, then restoring enough carbon to form steel. The impurities of the pig iron are carbon resulting from the coke used as a fuel, silicon, sulphur and phosphorus in the original ore. The pig iron is placed in a pear-shaped converter lined with a basic brick, usually magnesite, chromite or bauxite. At the bottom of the converter the air is introduced from a compressor at a pressure of about 25 lb. per square inch. The air forces its way up through the molten metal and oxidizes the impurities. Phosphorus, however, is not removed by this process. Ferromanganese or spiegeleisen, alloys containing a definite percentage of manganese, are then introduced in a molten condition. Instantly all the oxygen in the molten iron unites with the manganese while the carbon is taken up by the iron, and Bessemer steel is the resulting product. The steel is tough, elastic and widely utilized.

Space might be given to the details of the manufacture of foundry and forge iron, basic pig iron, charcoal iron, wrought iron, spiegeleisen and ferromanganese; also open-hearth steel, electro-metallurgy of iron and steel and a combination of the electro-open-hearth and electro-Bessemer processes. These fields, however, lie in the domain of metallurgy rather than in economic geology.

Uses of the Metal.—The uses of iron are too well known to be enumerated in detail. The larger uses fall into three distinct fields. 1. Railroad construction. 2. Bridge architectural construction. 3. The construction of vessels.

While there are many crucible steel plants scattered throughout the United States, Pittsburg and Syracuse are the only cities possessing more than one such plant. The chief product of the two crucible steel plants in Syracuse is high-grade tool steel and used largely for twist drills, taps, dies, punches, and high-speed steel which is standard not only throughout the United States but the world as well.

Another type of steel manufactured in Syracuse is magnet steel which up to the beginning of the present century was largely imported. This permanent magnet steel is largely used in electrical measuring instruments, telephones and magnetos.

The needle steel of Syracuse is widely used in domestic circles but it is also sent to England and Germany. The razor steel is sold in Solingen which is the cutlery center of Germany. The

crucible steel plants also manufacture annular ball bearings largely demanded by automobiles.

Electric-furnace steel is also manufactured in Syracuse and largely used in springs, gears, shafts, stearing knuckles, and all important parts of automobile construction. It is estimated that $3,000,000 is invested in the steel industry of the city and that it stands second in the country in the quantity of its output and first in quality of the steel manufactured.

An ore to be of value at the present state of the iron industry must occur in close proximity to a good market, must be of good quality and large quantity, and must be favorably situated for extraction and smelting. The most favorable location for such a mine is: (1) Near good coking coal for fuel. (2) Near limestone for a flux which should not contain more than 5 per cent. of magnesium carbonate. (3) Where economical methods of transportation exist. Unless these three requisites a e observed iron ores cannot be extensively mined with profit save where the ore is in great abundance and the most economical methods of transportation exist. Iron is now so cheap that where mine operations are difficult, as in deep mines, narrow veins, abundant gangue minerals, and difficult transportation, it cannot be mined with profit. There are enough good mines to make selection possible, but the iron of the smaller mine may be obtained by electrolysis which now bids fair to revolutionize the iron industry of the world.

The value of iron in the arts and industries depends upon the fact that it is abundant and cheap; that by different processes it can be made either brittle or malleable; soft, hard, or extremely tough. The hardness is varied by heating and tempering. Several metals such as chromium, nickel, molybdenum, titanium, vanadium, tungsten and manganese render steel extremely hard and tough.

Pig iron is converted into steel on account of the superiority of steel for structural purposes, and the ever-cheapening processes of its manufacture. Large engines, locomotives, cars, etc., are now made of steel rather than cast iron because of its superior strength and resistance.

Three countries, the United States, United Kingdon, and Germany produce more than three-fourths of the pig iron of the world and likewise approximately four-fifths of the world's production of steel. The United States alone produces more than

one-third of the world's yield of each of these commodities. The value of pig iron produced in the United States for the banner year of 1907 was $529,958,000.

Aluminum: Its Properties, Occurrence and Uses

Properties.—Aluminum, symbol Al, is a tin-white, lustrous metal. It is ductile, sectile and malleable. It is a good conductor of both heat and electricity. It is permanent in either dry or moist atmosphere. Aluminum is scarcely attacked by nitric acid, but is readily soluble in hydrochloric acid. It is extremely sonorous, for when struck it emits a clear and sustained note. It has a tensile strength of about 35,000 lb. per square inch. It is the lightest of all the useful metals. Its specific gravity is 2.58, melting point, 657.3° C., and its atomic weight is 27.1.

Ores of Aluminum.—Aluminum is the most widely distributed of all the metals, but it does not occur free and uncombined in nature on account of its remarkable affinity for oxygen. All of the aluminum minerals save the double fluoride, cryolite, are oxygenated compounds. It does not occur in nature alloyed with other metals. It is unlike all the other metals considered in this volume save gold in that its sulphide does not exist in nature. The most important source of many of the useful metals is the sulphide, but aluminum finds its most important ores like iron in the oxides and hydrous oxides.

Corundum, Al_2O_3, 52.9 per cent. Al. Distinguished from all other minerals, save the diamond, by its superior hardness.

Ruby, Al_2O_3, 59.2 per cent. Al. The red variety of corundum used as a gem.

Sapphire, Al_2O_3, 59.2 per cent. Al. The blue variety of corundum used as a gem.

Emery, xAl_2O_3, yFe_2O_3. The oxide of aluminum sometimes contains as high as 35 per cent. Fe. Magnetite may replace the hematite.

Diaspore, Al_2O_3, H_2O, 85 per cent. Al_2O_3.

Bauxite, Al_2O_3, $2H_2O$, 73.9 per cent. Al_2O_3.

Gibbsite, Al_2O_3, $3H_2O$, 65.4 per cent. Al_2O_3.

Cryolite, AlF_3, $3NaF$, 12.8 per cent. Al.

Turquoise, Al_2O_3, P_2O_5, $5H_2O$. The mineral is used as a gem.

Alunite, K_2O, $3Al_2O_3$, $4SO_3$, $6H_2O$.

Alunogen, $Al_2(SO_4)_3$, $18H_2O$.

The aluminum minerals may be divided into five distinct classes sollows: (1) Those used for the extraction of the metal; corundum, cryolite, bauxite and gibbsite. (2) Those used directly as gems; ruby, sapphire and turquoise. (3) Those used as an abrasive on account of their superior hardness; corundum, emery and diaspore. (4) Those known directly as alums or used in the manufacture of alums; alunogen and alunite, together with many natural alums. (5) The anhydrous and hydrous silicates bearing aluminum.

Aluminum occurs as an essential constituent of all important rocks, save the limestone, marbles, dolomites and sandstones, and even here it is a common impurity. It is present in all the micas and feldspars that have wide industrial application. It is a necessary constituent of all clays.

Origin of the Ores.—Corundum and its varieties occur both as primary and secondary minerals. According to F. W. Clarke the most important experiments from a geological standpoint upon the genesis of corundum have been conducted by Morozewicz. Morozewicz worked indefatigably upon large artificial magmas, using the furnace of a glass factory in the preparation of his melts; and he found that whenever the alumina in comparison with the other bases exceeded a certain ratio, the excess upon cooling crystallized out completely as corundum, as spinel, as sillimanite, or as iolite, dependent upon percentages. Previous to the appearance of Morozewicz's memoir, corundum was not supposed to be a pyrogenic mineral but a product of contact matamorphism, especially in limestones. (See Fig. 116.)

According to J. H. Pratt corundum occurs in North Carolina and Georgia as a pyrogenic mineral from the fractional crystallization of a peridotite magma, rich in the ferromagnesian mineral olivine. Corundum has been observed as a primary mineral in both pegmatites and syenites, but these occurrences are rare.

Corundum, of secondary origin, is a product of contact metamorphism and is generally associated with shales and limestones. Emery is perhaps best regarded as a variety of corundum. It consists of corundum admixed with hematite, magnetite, and sometimes spinel.

The hydrous oxides, diaspore and gibbsite are often formed by the hydration of corundum. Bauxite, according to C. W. Hayes belongs to the hot spring deposits. Percolating meteoric waters have converted pyrite, the sulphide of iron, into melanterite,

the green sulphate of iron. During the process the sulphuric acid has attacked the alumina in the shales. These solutions traversing limestones would find the calcium carbonate reacting upon the aluminum sulphate solutions according to the equation

$$Al_2(SO_4)_3+3CaCO_3=Al_2O_3+CaSO_4+3CO_2.$$

The gelatinous precipitate thus formed is carried upward in spring basins where it finally settles as a pisolitic mineral. In

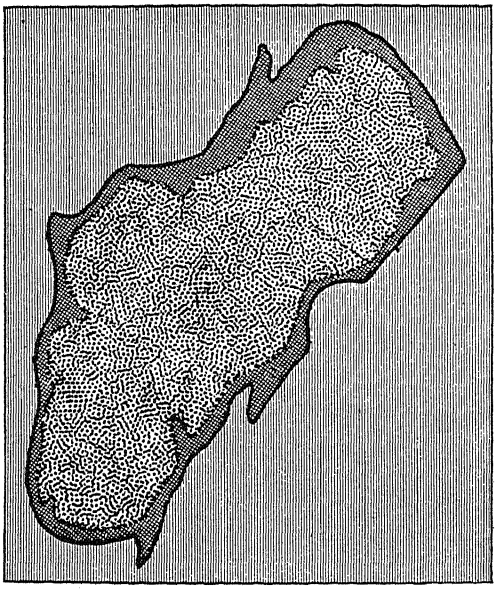


Fig. 116.—Map showing the occurrence of corundum as a differentiation product of peridotite. (*After Thomas and MacAlister's Geology of Ore Deposits.*)

the absence of the calcium carbonate to react upon the hydrous sulphate of aluminum the alums would be formed in the above process of alteration. Waters containing the sulphates of iron and aluminum form deposits of these salts in close proximity to their points of origin. They are commonly found as stalactites and even as incrustations. Alunite and alunogen are the commonest species thus generated. They are found around mineral springs and in the shafts or tunnels of mines.

The silicates of aluminum occur both as primary and as

secondary minerals but their discussion belongs with the non-metallics.

Character of the Ore Bodies.—Corundum occurs as oval or lenticular ore bodies near the margin of peridotites or norites. They differ in many respects from those formed by the thermal metamorphism of sediments. There is usually a complete absence of such metamorphic minerals as cyanite, which plays an important part in the corundum deposits of Siam where the ore is a product of metamorphism. In the case of the peridotites the alumina was dissolved in the original magma at the time of

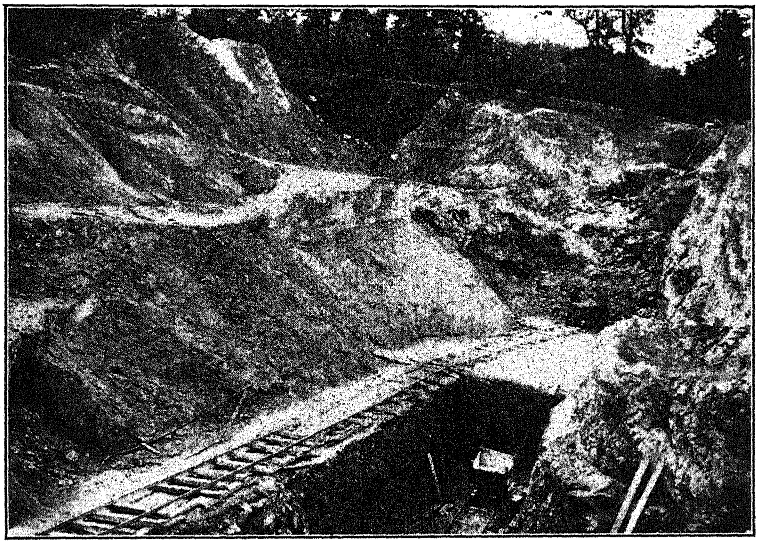


FIG. 117.—View of Bauxite bank, Rock Run, Alabama. (*By permission of the Macmillan Company, from Ries' Economic Geology.*)

its intrusion into the country rock and then separated forming lens-shaped masses at an early stage as the magma began to cool.

Alumina is also soluble to some extent in molten magnesium silicates, and if the magma has no excess of magnesium all the aluminum will crystallize as corundum, but if there be a slight excess of magnesium over that required for the magnesium silicates then spinel will be formed.

Corundum occurs as a contact deposit between some intrusive and limestones or shale. In Massachusetts at Chester corundum and emery occur in a large vein consisting mainly of emery,

magnetite and diaspore, in association with repidolite and margerite, and traversing metamorphics.

Rubies occur *in situ* in the limestones of Upper Burma, north of Mandalay, also in the soils upon the adjacent hillsides and in the gem-bearing gravels of the valleys. Gem sapphires are found near Helena, Montana, in the gold washings and in the various bars in the Missouri River.

Bauxite occurs in pockets or lenses of variable length and breadth (Fig. 117). It may be either pisolitic or clay-like in structure, white or red in color. All of the red varieties are rich in iron. Gibbsite in Arkansas is of the granitic type and rests upon a bed of clay derived from an elaeolite syenite, from which also the gibbsite was probably derived. The alums occur as incrustations and sometimes as stalactites around mineral springs and at the entrance to mines.

Cryolite occurs in a large bedded deposit in Greenland which F. Johnstrup regards as a concretionary secretion in eruptive granite. Cryolite is found sparingly in the granites of Pikes Peak, Colorado, and at Miask in the Ural Mountains.

Geographical Distribution.—There are many scattered occurrences of corundum and its associated minerals along the Appalachian belt from Dudleyville, Alabama, to Greenwood, Maine. The mines of the greatest commercial significance are located at Laurel Creek, Georgia, and Corundum Hill, North Carolina. It occurs at Unionville, Pennsylvania, in masses weighing 4,000 lb. Here it is associated with tourmaline, margerite and albite. The deposits at Chester, Massachusetts, have been operated for a considerable period of time in the manufacture of the well known Chester emery. Emery, magnetite and diaspore enter into the finished product, under the name of emery. Probably the largest deposits of emery in the world are found on the Island of Naxos in the Grecian Archipelago and in Asia Minor where the ore deposits are supposed to be the product of metamorphism.

There are five distinct districts of commercial bauxite in the United States. (1) Wilkinson County, Georgia, district; (2) Georgia-Alabama district; (3) Tennessee district; (4) Arkansas district; and (5) New Mexico district.

(1) According to A. C. Veatch commercial bauxite occurs in Wilkinson county, Georgia, near the margin of the Coastal Plain. The beds have a maximum thickness of 10 ft. and lie near the con-

tact of the Lower Cretaceous and Tertiary formations. The ores are generally pisolitic or concretionary, but sometimes they are amorphous and flinty. Veatch considers that the ore was formed by a desilicification of the kaolinite in the associated clays by circulating meteoric waters carrying some chemical capable of extracting the silica from the hydrous aluminum silicate (Fig 117).

(2) In the Georgia-Alabama district the bauxite deposits extend from Cartersville, Georgia, to Jacksonville, Alabama, a distance of about 60 miles (see Fig. 118). They are found at altitudes

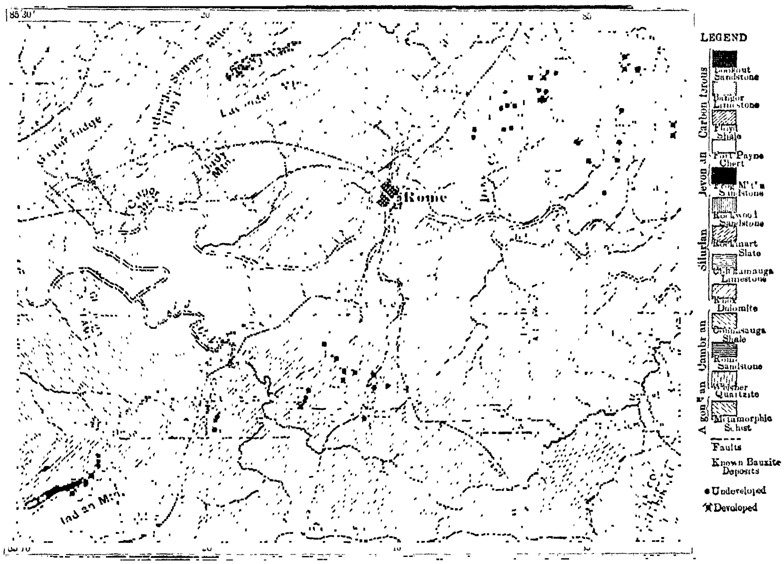


FIG. 118.—Geologic map of Alabama—Georgia bauxite region. After Hayes. (*By permission of the Macmillan Company, from Ries' Economic Geology.*)

varying from 850 to 950 ft. above sea level. The ores are pisolitic, or clay-like. They form pockets or lenses of variable breadth and thickness in the residual clays derived from the underlying limestone. According to C. W. Hayes the bauxite belongs to the hot spring deposits. The Connasauga shales underlying the Knox dolomite are thousands of feet in thickness and bear pyrites. Percolating meteoric waters acting upon the sulphide of iron produced sulphuric acid. The sulphuric acid attacked the aluminiferous shales forming the sulphates of iron and aluminum. These solutions were transported upward through the Knox dolomite

where the calcium compounds in the dolomite produced alumina amd calcium sulphate. The aluminum compound which was light and gelatinous was carried upward into spring basins on the surface where it finally settled.

(3) The bauxite deposits of the Tennessee district are situated near Chattanooga, on the southeast slope of Missionary Ridge. They came into prominence in 1907. According to H. Ries they represent the northward extension of the Georgia-Alabama district.

(4) The bauxite deposits of Arkansas are confined to a small area in Pulaski and Saline Counties. These ores have been carefully studied by C. W. Hayes, J. C. Branner, and J. F. Williams, who state that the ores are found in Tertiary areas in the neighborhood of irruptive syenites and in a region free from limestones. There are two varieties of the ore. The one is granitic, and the other pisolitic. The granitic variety shows the structure of the syenite from which it was probably derived. The pisolitic variety was doubtless deposited from solution. The three authorities agree in tracing the genesis of the bauxite back to the action of waters upon the heated syenite. Hayes believes that these waters were either alkaline or saline, that they dissolved out the silica and the alkalis and deposited alumina in their places. Fourche Mountain, which constitutes one of the bauxite areas, is the home of elaeolite syenite and both diaspore and gibbsite are recognized as decomposition products of elaeolite and sodalite.

According to F. W. Clarke, bauxite is intermediate between diaspore and gibbsite and represents an admixture of the two hydrates, sometimes approaching one in composition and sometimes the other. The granitic type above referred to very closely conforms to gibbsite, while the pisolitic type may more nearly represent $Al_2O_3,2H_2O$. One variety of the bauxite is high in silica and low in iron, while the other has been worked as an iron ore on account of its high percentage of iron.

(5) Bauxite deposits occur in the vicinity of Silver City, New Mexico, which appear to have been derived from a basic volcanic rock *in situ*. These ore bodies are some distance from the railroad and therefore are not extensively worked.

The type locality for bauxite is the town of Baux in the southern part of France. It is from this district that the mineral derives its name. At Baux the ore occurs in irregular masses in Cretaceous limestones where it has been deposited through the

agency of mineral springs. The action which brought about the precipitation was doubtless metasomatic and dependent upon the limestone.

According to Thomas and MacAlister metasomatic bauxite deposits occur in the Puy de Dôme district of Central France, and in the northern part of Ireland in association with basaltic rocks from which they were evidently derived.

Geological Horizon.—The ores of aluminum are not confined to the rocks of any particular age. Corundum and emery are more abundant in the older geological formations as the pre-Cambrian, Cambrian and Ordovician. The bauxite deposits of Arkansas are in part as late as the Tertiary.

Methods of Extraction.—Aluminum was isolated for the first time in 1827 by Wohler by means of the effect of potassium upon the anhydrous chloride. Commercially it has been obtained in large quantities by the ignition of cryolite with sodium or potassium. Two processes have been used to produce commercial aluminum: The chemical process, and the electrolytic process.

(1) In the chemical process the chloride of the metal is fused with the double fluoride, cryolite, in the presence of metallic sodium or potassium when elemental aluminum results from the reducing action of the sodium or potassium. It has been produced commercially without the aid of an alkali from a mixture of clay, cryolite, bauxite, with carbon and carbon disulphide.

(2) In the electrolytic process a mixture of corundum, cryolite and bauxite have been subjected to the intense heat of an electric furnace. A carbon-lined crucible has served as the cathode and a bundle of carbon rods as the anode. The metallic aluminum collects at the bottom of the crucible.

Uses of Aluminum.—Aluminum is used in many forms in the minor as well as the grosser industries, in articles useful, or luxurious. It is used in the manufacture of keys, visiting cards, pocket calenders, thimbles, brushes, combs, letter cases, cigar cases, cigarette cases, for which the metal is highly valued on account of its extreme lightness.

It is used in the manufacture of opera glasses, spectacles, knives, watches, and many articles of adornment. It finds a use in household utensils such as cups, saucers, plates, chafing dishes, tea urns, etc. It is used in individual communion sets, also in the manufacture of a large number of toys. It is utilized in the alums in medicine. It is used in the springs in shoes. Alum-

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inum is used in the manufacture of camp equipment, where special lightness and non-corrosiveness are desirable. The metal is used also in the manufacture of army equipments as shells for cartridges, drum heads for the Austrian army. It was tried in drum heads in the United States during the Spanish-American war, but this use was not desired by the American soldier.

Aluminum is used extensively for pigments. By the introduction of a small quantity of aluminum a paint is formed which is more impervious to the action of the corrosive gases of the atmosphere or a laboratory than almost any other pigment. The metal is used in silvering letters and signs.

Aluminum is used in the reduction of refractory metals to the elemental state. Copper, chromium and iron are very readily reduced to the metallic state through the influence of aluminum. It is used also in lithography where it displaces limestone and zinc for stock patterns for foundry work. It is used extensively for boat building and marine engineering. It was utilized in the manufacture of vessels for the Madagascar campaign for France and the vessels were returned to France exceedingly well preserved. Under certain conditions of cleanliness a progressive disintegration of the metal can occur. In England aluminum was not generally adopted for the army. In India the government adopted the metal for this work in 1902. The report of the German Admiralty authorities was that aluminum remains unattacked in the presence of both air and sea water. It is used in light boat building. The international racing yachts, the Columbia and the Shamrock, each contained large quantities of aluminum. The Shamrock was lined with aluminum to the water line. The deck plating and the top staff were also aluminum.

The numerous uses of aluminum in metallurgy, whether in the form of the metal or in a pulverulent state, depend upon its remarkable affinity for oxygen and its power to rob all other metals of this element when in contact with them under the right condition of heat.

In 1901 the United States purchased 10,000 blanks the size of a nickel presumably for coinage. Such coins would be light and should wear well. Aluminum is used in the New York telegraph and telephone wires. These have stood the ravages of many winters without failure. It is used extensively for such purposes in high altitudes where the snows are heavy and deep.

The specific heat of aluminum melts the snow as it falls upon the wire, therefore the wires do not stretch and break under the burden of the snow like copper wire The electrical conductivity of aluminum is double that of copper per pound. therefore it has a superior advantage for electrical purposes wherever the wires are subject to severe storms.

The general post-office authorities of England have introduced aluminum into their long-distance communications. The large increase in the domestic consumption of the metal is largely due to the use of aluminum for electrical conductors, and the ease with which it replaces zinc in brass. The electric lines in Chicago have in part substituted aluminum wires for copper and these are giving perfect satisfaction.

Among the newer uses of aluminum is that for the production of intense heat by the combustion of the metal in the form of the powder called thermit, which is the base of three important branches of metallurgy. It is used in the manufacture of a special explosive called amonal. It is used in the rubber industry for making lasts and boot trees upon which rubber boots and shoes are manufactured. It is used as a substitute for wood in making bobbins for spinning and revolving machinery used in the manufacture of silk fiber. It is used as a substitute for glass and many forms of earthern ware, in carboys employed for the transportation of nitric acid, as a substitute for zinc in the linings of cisterns and other receptacles for storing water.

Aluminum alloys readily with other metals both common and rare, and furnishes many useful alloys. The number of these light alloys now upon the market is large. The metal itself is so soft when produced by electrolytic methods that some hardening element is very desirable. Silicon possesses this factor whether present accidentally or added intentionally. If more than 2 per cent. silicon is present it impairs the malleability of aluminum but does not diminish its value in castings. Aluminum bronze containing 10 per cent. or less of aluminum is largely used in the arts. It is commercially used as aluminum gold. As it contains no tin it is not, strictly speaking, a bronze. Bronze with 5 per cent. aluminum closely resembles pure gold. With 10 per cent. aluminum the alloy is a little darker than 22 carat gold. With a larger percentage of aluminum the alloy whitens. With more than 15 per cent. aluminum the alloy becomes white.

Many of the aluminum alloys have a tensile strength ranging

from 83,000 to 91,000 lb. per square inch. One alloy is said to have a tensile strength of over 100,000 lb. per square inch. Aluminum bronze can be rolled into thin sheets, readily drawn out into wire, spun, stamped, or pressed like ordinary brass. It is extremely tough and malleable. Its smoothness enables it to resist abrasion so that it is adapted for use as an anti-friction metal. It resists corrosion far better than the bronzes and tarnishes less readily upon exposure to moist atmosphere. According to Sexton it can be kept at a red heat for months without showing any signs of oxidation. The alloy is well adapted for use in jewelry on account of its color, and for many parts of machinery on account of its tensile strength, for propellor blades for ships on account of its strength and non-corrosiveness, and for the castings of heavy guns on account of its strength. The strongest aluminum alloy known is said to consist of 27 per cent. copper, 10 per cent. aluminum and 3 per cent. silicon. Many alloys of aluminum containing 10 per cent. or less of copper are widely used where lightness, strength and non-corrosiveness are desired. Magnalium is an alloy of aluminum with magnesium. It is lighter than pure aluminum with specific gravity of 2.4. It is ductile and malleable. It can be spun, drawn or forged like aluminum. It is non-corrodible and has a tensile strength of 42,000 lb.

Ferro-aluminum is an alloy of aluminum and iron used largely in the manufacture of steel. It is a yellowish white alloy, hard and brittle. Aluminum unites with tin in the formation of a series of useful alloys especially for optical instruments in the place of brass. These alloys can be used in the place of aluminum wherever lightness is desired. Aluminum and zinc form important alloys. If a small amount of aluminum be added to zinc it renders the metal more fluid. It therefore increases the area a given amount of zinc will galvanize. It also reduces the amount of oxidation that may occur. With 18 per cent. of zinc the alloy is easily worked and of technical value. Aluminard is an alloy of copper, nickel, zinc, and phosphorus. It takes a polish equal to aluminum and is used in the castings for delicate machinery. Partinium is a new alloy patented at Putaux, France. It is designed for the bodies of steam omnibuses, bearings of engines and shop shaftings. Aluminite is a fire-proof flooring used extensively in kitchens, halls and grill rooms. It makes a light soft flooring.

Bauxite is used in the manufacture of aluminum, aluminum sulphate, alums, etc., and in the linings of furnaces on account of its refractoriness. The low ocean freight rates from foreign ports allow bauxite to be delivered, duty included, from the southern part of France to New York, Philadelphia, or Baltimore, at a lower rate than it costs to ship bauxite from Alabama, Georgia, or Arkansas to Philadelphia. French bauxite can be delivered in Philadelphia at $0.55 per ton cheaper than the American bauxite can be supplied to the same market and in Boston for $1.70 per ton cheaper than the home product can be delivered in the same city. One reason for the advantage the French bauxites have over the American is that they do not have to be quarried. The richest mines are in the southern part of France in the neighborhood of Baux, 30 miles from the coast. Three kinds of bauxite exist in the district: Ferruginous, spotted, and aluminous. The demand for the first is small on account of its iron content. The spotted variety contains 21.99 per cent. of iron oxides and 60 per cent. of the aluminum oxide. The third variety is the one most sought because the iron and silica are both low and the aluminum is higher than in the other varieties. In order to carry on the bauxite industry with profit, works should be established with modern appliances so that the various salts of aluminum and the aluminous refractory compounds may be manufactured.

Cryolite is used in the manufacture of hydrofluoric acid, the various fluorides of commerce, some sodium salts, and also as a source of aluminum. The fluorides are sold to smelters and glass manufacturers except the sodium fluoride which is shipped directly to Europe and India, and used in the manufacture of opalescent glass which closely resembles French porcelain. The glass is extremely hard and tough and can be worked as easily as ordinary glass.

The Pennsylvania Salt Company has at times possessed the sole power to import cryolite into the United States and South America. The supply is controlled by the Danish government. There are no commercial deposits of cryolite in the United States, although it is found near Pikes Peak, Colorado, and in Yellowstone National Park. The value of the Ivigtut cryolite is $80 per ton, determined as follows: (1) Cost at the mine in Greenland. (2) Royalty to the Danish government. (3) Ocean freight rates. (4) Domestic freight rates. (5) Cost of concen-

tration. (6) Cost of grinding and packing in barrels. (7) Other minor expenses.

Chromium: Its Properties, Occurrence and Uses

Properties.—Chromium, symbol Cr, is a hard steel-gray metal permanent in dry atmosphere, even in minute quantities. Unlike iron it is non-magnetic. The magnetism sometimes feebly present in the chief ore, chromite, is due to the ferrous oxide present in the mineral. Chromium is soluble in HCl. It imparts great hardness and tenacity to steel. Its specific gravity is 6.8. Its melting point is 1515° C. Its atomic weight is 52.1.

Ores of Chromium.—The metal does not occur free and uncombined in nature on account of its affinity for oxygen. The chromium minerals are therefore oxygenated compounds.

Chromite, Cr_2O_3,FeO, 68 per cent. Cr. The ferrous iron may be replaced by manganese and the chromium by ferric iron and aluminum.

Chrome ocher, Cr_2O_3. A bright green mineral bearing some clay.

Crocoite, $PbCrO_4$. A rare mineral in varying shades of hyacinth red.

The first mentioned mineral, chromite, is the sole source of the metal of commerce. It is widely diffused in the basic igneous rocks rich in magnesium. It has been found in placers derived from their decomposition. It has been observed adherent to an interpenetrating platinum magnet. The rare mineral, *daubreelite*, Cr_2S_3,FeS, has been observed in several meteorites.

Origin of the Ores.—S. Meunier has suggested that whenever an alloy of chromium and iron is brought up from the zone of flowage it oxidizes as it nears the surface. The theory is objectionable because no such alloy is known to exist in nature. Chromite is essentially a primary magmatic mineral. It is one of the first minerals to segregate from an ultra-basic magma like peridotite. Its associate in this differentiation is magnetite. Microscopic slides of the magnetites and chromites of northern Vermont and Megantic County, Quebec, have been prepared to ascertain which of these ores solidified first but the problem is still unsolved. Ore bodies sufficiently large to be of commercial significance are definitely recognized as a product of magmatic

differentiation in northern Vermont and Megantic County, Quebec. The mines in the Canadian territory are still worked, but those in Vermont are idle, although a considerable amount of ore was at one time mined in the town of Troy. The larger ore bodies of Pennsylvania lie in the same peridotite belt and possess the same mode of origin. J. H. Pratt has assigned magmatic segregation to the chromite deposits of the southern Appalachians. Chrome ocher may result from the alteration of chromite.

Character of the Ore Bodies.—Chromite occurs in irregular pockets, veins, and lens-shaped masses segregating near the periphery of a peridotite magma. It is also found in placers in association with platinum where it has been derived through the decomposition of peridotite.

Geographical Distribution.—There are two distinct belts of chrome iron ore in the United States: The Appalachian district and the California district.

The first of these districts may be subdivided into three distinct fields. The southern lies in north Carolina and Maryland; the central has reached its best development in Pennsylvania and the third in northeastern Vermont and Canada. Deposits of chromite occur in the western part of North Carolina and in Baltimore County, Maryland, but these ores are no longer worked. The Wood's mine in Lancaster County, Pennsylvania, was opened in 1828 and worked continuously until 1869, when the mine filled with water. At one time this mine produced practically all the chromite in the world. The ore was also worked at one time in Chester and Delaware Counties, but these mines have also been abandoned. Chromite ores were worked in the early 60's in the northeastern part of Vermont, but distance from the railroad led to the abandonment of these mines also. In Megantic County, Quebec, and in Newfoundland where the ores occur in the same peridotite belt they are still extensively mined.

In the California district the deposits of chromite reach their best development in San Luis Obispo and Shasta Counties. In the former county the mines like those of the Appalachian belt have been abandoned. The ores of Shot Gun creek in the latter are still worked for their chrome content. According to H. Ries the ore occurs in serpentine in a series of five lenses, each containing from 200 to 1500 tons of chromite. Each lens is connected by vein-like stringers in a nearly vertical shear zone. The ore con-

tains 43.87 per cent. of chromic oxide. In 1908 an important deposit of chromite was discovered in Converse County, Wyoming.

The most important chromite deposits of the world are found in Asia Minor. According to Thomas and MacAlister the ore exists as stocks or dike-like masses, and ultra-basic patches in serpentine formed from the alteration of peridotite. Similar deposits exist in the neighborhood of Kraubat, in Upper Styria. It occurs also in a fairly fresh peridotite in Norway. In New Caledonia, deposits are commercially increasing in importance. The deposits of chromite in Southern Rhodesia are peculiarly interesting, for they are associated with platinum in small proportions with the sulphides of cobalt and nickel.

Geological Horizon.—Chromite is confined in its workable ore bodies to the pre-Cambrian, Cambrian and Ordovician deposits. Therefore its association is with the older ultra-basic intrusives.

Methods of Extraction.—The electrolytic method: The ore is crushed and fashioned into a large crucible where its complete electrolytic reduction requires one hour. The only manufacturers of chromium in this country are the Baltimore Chrome Works at Baltimore, Maryland, and the Kalion Chemical Works at Philadelphia, Pennsylvania. Much of the ore treated at Baltimore comes from Scotland, and for Philadelphia from Quebec and Newfoundland.

Uses of Chromium.—Raw chromite is used in the manufacture of refractory brick. These bricks are used for lining basic, open-hearth furnaces in the steel industry and as a hearth lining for water-jacket furnaces in modern copper smelting. Its merits are as follows: It is infusible; it does not become friable when heated and cooled; is unaffected by sudden heating and rapid cooling; is not affected by the products formed in the fusion of copper ores; it wears away very slowly under the flow of the molten metal. Its use should continue to increase, for the life of the brick is many times greater than that of any other refractory linings and bottoms in the iron or copper industries. This use has been thoroughly tested in the water-jacket furnaces both in New England and in Tennessee. The chromite deposits therefore of California should find extensive use in the furnaces for the treatment of the various copper ores in the Cordilleran section. In the linings of one furnace where raw chromite was used over 400 heats were turned out before the basic chromite bricks had to be repaired or removed. Therefore

the manufacture of refractory bricks in various forms, owing to its own refractoriness, will demand a larger use for chromite than the known American deposits can supply. Chromite brick are made of chromite and coal tar or some other binding material. They are superior to magnesite brick in many particulars.

Chromite is used as a mordant in producing shades of red, green, buff, brown and black. Chromium is used in the manufacture of the red and yellow chromates for commercial trade and in electrolysis. Some of the chromates are used directly as a pigment. Chromium salts are used in printing, dyeing, and in wall paper. Chromium is also used as an oxidizing agent and in tanneries. Chrome-tanned leather will resist the heating of high-speed belts than any other leather known. It will stand a harder usage. Chromium is also used in the manufacture of pottery. Some chromium salts find a use in medicine.

Chromium is used in the manufacture of steel. Here its special value is its freedom from carbon, and by its use steels high in chromium and low in carbon can be manufactured. Such steels are extremely hard and tough, resist shocks and are of great tensile strength. They are especially to be desired wherever these properties play an important part. It is sometimes stated that scales of chromium separate out and make such steel incapable of welding and that only an adhering union results. However, the welded zone is equally as strong as the unbroken steel.

Chromium is used very largely in the manufacture of alloys. The ferro-alloy is used with ferro-nickel in the manufacture of chrome steel for armor plates, and armor-piercing projectiles, trolley car wheels, crusher jaws, stamp mill shoes, so-called burglar proof safes, tires, axles, springs, magnet steel, cutlery, mechanical implements and bridge steel.

The ferro-chrome alloy is produced under the intense heat of an electric furnace from high-grade chrome ores low in silicon. The iron, chromium, tungsten and nickel alloy is especially valuable for high-speed tools on account of its resistance to heat and abrasion.

The value of chromite depends largely upon the percentage of chromic oxide, Cr_2O_3 present. The standard ore contains 50 per cent. of this oxide. It increases in value $1 per ton for every unit above 50 per cent. It decreases in value for every unit less than the standard 50 per cent. When the percentage of chromic

oxide falls below 30 per cent. it decreases at a far more rapid rate. Ores carrying from 40 to 50 per cent. of the oxide are readily marketable provided they are low in silicon. In spite of the value of the metal in its numerous alloys and its wide application in pigments the output is exceedingly small and most of the ores are imported.

CHAPTER VIII

USEFUL METALS CONTINUED (GROUP IV)

COBALT, NICKEL, MANGANESE, ZINC

Cobalt: Its Properties, Occurrence and Uses

Properties.—Cobalt, symbol Co, is a hard, bluish-white metal somewhat suggestive of nickel, but without its characteristic yellowish tinge. At a high temperature, unlike iron and nickel, it retains its magnetism. The metal is malleable, sectile, and very ductile when heated. In the massive form it is permanent in ordinary atmosphere but when in the pulverulent state it is rapidly oxidized. Its specific gravity varies from 8.54 to 8.7. Its melting point 1530° C. Its atomic weight is 58.97.

Ores of Cobalt.—Cobalt occurs in the native state in very small quantities in meteoric iron.

Jaipurite, CoS, 64.6 per cent. Co. Used in enameling various shades of blue on gold and silver.

Linnæite, Co_3S_4, 21.34 per cent. Co. If none of the cobalt were replaced by nickel the theoretical per cent. of cobalt would be 57.9.

Smaltite, $CoAs_2$, 28.2 per cent. Co. Usually with some nickel present.

Safflorite, $CoAs_2$, 28.2 per cent. Co. Nickel and iron present in varying amounts.

Skutterudite, $CoAs_3$, 20.7 per cent. Co. With traces of iron.

Cobaltite, CoS_2, $CoAs_2$, 35.4 per cent. Co.

Erythrite (cobalt bloom), $3CoO,As_2O_5,8H_2O$, 37.47 per cent. Co.

Asbolite (black cobalt ocher). Composition variable.

Cobalt is widely diffused in the igneous rocks but in much smaller quantities than its associate nickel. It is present also in both the meteoric and terrestrial iron. It has been found also in the ashes of sea weeds.

Origin of the Ores.—The sulphides of cobalt may be formed by either the wet or the dry processes. The arsenides of cobalt

according to F. W. Clarke do not represent igneous segregations. They may have been leached out from their accompanying eruptive rocks, or may have been brought up from below. The sulphate and carbonate of cobalt are secondary minerals. Erythrite arises from the oxidation and hydration of the arsenides and is a common mineral in the oxidized zone of ore bodies bearing cobalt as arsenides in the lower levels. Asbolite is an alteration product of cobaltiferous ores and in many respects closely resembles wad, or bog manganese.

Character of the Ore Bodies.—The principal ores occur in well-defined fissure veins traversing both intrusives and much-altered sedimentaries. The chief gangue mineral is calcite.

Geographical Distribution.—The cobaltiferous arsenopyrites are widely scattered along the Appalachian belt. Analyses of this variety, called danaite, from Franconia, N. H., gave 6.45 per cent. cobalt. The scattered occurrences of nickeliferous minerals in the Cordilleran section bear cobalt.

The most important cobalt deposits of America are found in the Province of Ontario, Canada, near the boundary line of Quebec and west of the northern end of Lake Temiskaming. It was during the construction of the Temiskaming and Northern Railroad that the deposits of cobalt and silver minerals at Cobalt were discovered. This was followed by a similar discovery at South Lorrain and another at Gowganda. These fields have given to Ontario a position amongst the leading silver camps of the world.

The geological section at Cobalt has as its base a series of highly folded diabases, granite porphyries, etc., that are intruded by granites. This series is Kewatin in age. This series of terranes is separated from the Lower Huronian conglomerates and slates by an erosional unconformity. Above the Lower Huronian rocks is a series of conglomerates, quartzites and arkoses of Middle Huronian age. Post-Middle Huronian diabases appears in sheets and sills. Above the diabases there occurs Niagara limestones and glacial drift completing the geological section. The ores occur in the conglomerates, the diabases and the underlying Kewatin series, although the lower formations are not so productive of silver and cobalt.

According to W. G. Miller the ores were deposited by highly heated impure waters circulating through the cracks and fissures following the intrusion of the post-Middle Huronian diabase.

Two possible sources of the ores are suggested. (1) The metals may have been brought up from great depths by these waters. (2). The metals may have been leached out of the disturbed and folded Kewatin series of terranes. The arsenides appear to have been the first minerals deposited, after which the veins suffered some disturbance which resulted in the formation of cracks and minute fissures favoring the deposition of the silver at a later time. A proof that disturbance preceded the deposition lies in the fact that the silver cuts the arsenides and that the undisturbed veins are non-argentiferous. The veins are small, varying from 1 in. to 1 ft. or more in thickness. Some of them are of remarkable richness. A single sample from the Gowganda camp assayed by E. E. Burlingame & Co. of Denver, Colorado gave 27,066 oz. of silver per ton of ore.

Geological Horizon.—The commercial deposits of cobaltiferous minerals are found in the older geological formations from the pre-Cambrian to the Ordovician.

Method of Extracting.—The ores are roasted, smelted into a matte, and subsequently refined by electrolysis.

Uses of Cobalt.—Metallic cobalt finds little application in the arts and industries. Cobalt steel has a high elastic limit and tensile strength but it is far more costly to manufacture than manganese or nickel steel and therefore does not possess so wide an industrial application.

Cobalt is extensively used as a pigment in the manufacture of glass and pottery. The beautiful blue color known as smalt blue is imparted to the glass by the oxide of cobalt. Zaffre, the roasted cobalt ore, cobalt oxide, arsenide, phosphate and sulphate are used in the coloring of glass and the painting of porcelain. Sympathetic inks are made of cobalt acetate and cobalt nitrate. These inks are colored when heated and colorless when cold. This is said to be due to a change in the color of the salts upon the absorption of water. Cobalt and potassium nitrate are used as an oil and water pigment for painting on glass and porcelain. Cobalt nitrate is used in medicine. The salts of cobalt are an antidote for the deadly prussic acid. The nitrate of cobalt is also used in chemical mineralogy in the detection of aluminum, tin, zinc and magnesium. Cobalt is also used in storage batteries but it is expensive for that purpose. Cobalt is used in the manufacture of gold and silver ornaments.

The banner domestic production including cobalt oxide in

ore and matte came in 1903 with 120,000 lb. Since 1908 the output has been included with nickel.

Nickel: Its Properties, Occurrence and Uses

Properties.—Nickel, symbol Ni, is a lustrous white metal with a faintly yellowish tinge. The metal is ductile, malleable and sectile but extremely hard and tenaceous. It is permanent in the massive form in dry atmosphere but in the presence of moisture it quickly becomes coated with a film of the oxide, NiO. The metal is magnetic but loses this property at high temperatures. It is soluble in mineral acids. Its specific gravity when cast is 8.35 and 8.6 to 8.9 when rolled. Its melting point is 1484° C. Its atomic weight is 58.68

Ores of Nickel.—*Native nickel,* Ni, 100 per cent. Ni. Often alloyed with iron.

Millerite, NiS, 64.6 per cent. Ni. Occurring in capillary crystals and tufted coatings.

Beyrichite, Ni_3S_4, 54.23 per cent. Ni.

Polydimite, Ni_4S_5, 59.4 per cent. Ni.

Pentlandite, $(Fe, Ni)S$, 22 per cent. Ni.

Pyrrhotite, Fe_nS_{n+1}. Sometimes containing 6 per cent. nickel.

Niccolite, $NiAs$, 43.9 per cent. Ni.

Chloanthite, $NiAs_2$, 28.1 per cent. Ni.

Rammelsbergite, $NiAs_2$, 28.1 per cent. Ni.

Gersdorffite, $NiAsS$, 35.4 per cent. Ni.

Annabergite, $3NiO,As_2O_5,8H_2O$ (nickel bloom).

Garnierite, $(Ni,Mg)O,SiO_2,H_2O$.

Genthite, $2NiO,2MgO,3SiO_2,6H_2O$.

To this list there might be added the terestrial minerals, awaruite, $FeNi_2$, which occurs in the drift of George River, emptying into Awarua Bay on the west coast of the south island of New Zealand; Josephenite, $FeNi_2$, from Josephine County, Oregon, and the nickel alloy $FeNi_3$ as found in the auriferous sands of the stream Elvo, near Biella, Piedmont, Italy.

Origin of the Ores.—Nickel occurs in both the terrestrial and meteoric irons. Some of these are best classified as nickel alloys for the percentage of nickel exceeds that of the iron. Nickel is one of the commonest of the minor constituents of the igneous rocks. According to F. W. Clarke in 262 analyses of

igneous rocks made in the laboratory of the United States Geological Survey an average of 0.0274 per cent. nickel oxide was found. The sulphides and the arsenides of nickel may be formed by either the wet or the dry processes. Where capillary millerite appears on dolomite crystals lining geodes it is unquestionably crystallized from solution. Where it occurs as a radiating incrustation upon secondary minerals as in Pennsylvania, it too must be of secondary origin (Fig. 119).

The origin of nickeliferous pyrrhotite is perhaps an open question. According to J. H. L. Vogt it represents a distinct segregation from a molten magma. This has long been considered the origin of the Sudbury, Ontario, pyrrhotite. The order of segregation has been most carefully studied by R. Bell, H. B. von Foullon, T. L. Walker, A. P. Coleman, A. E. Barlow and others. The order suggested is chalcopyrite near the wall rock, then pyrrhotite bearing nickel, and lastly nickel sulphide; the matrix being norite. According to D. H. Browne the occurrence of the ores at Sudbury is comparable to the phenomena observed in a cooling copper-nickel matte, in which the copper sulphides concentrate along the margins of the mass, and the nickel sulphides at the center (Fig. 120).

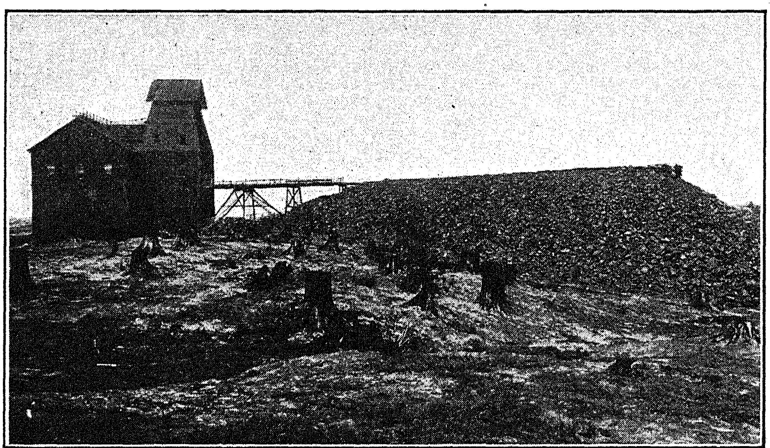

FIG. 119.—Evans mine, Canadian Copper Company, Copper Cliff, Ontario. (*After A. E. Barlow, Canadian Geological Survey.*)

According to W. Campbell and C. W. Knight the Sudbury ores were all formed from solution. The order given is as follows:

First magnetite, then pyrite and gangue, then pyrrhotite. The mass is then fractured and in the cracks there appears pentlandite. These ores are all fractured and in the cracks thus formed chalcopyrite is deposited.

According to F. W. Voit the nickel ores of Dobschau, Hungary, were deposited from solution in a gangue of calcite at or near contacts of diorite. C. R. Keyes considers the nickel mineral, linnæite at Mine La Motte, Mo., of secondary origin. It occurs in limestones as a metasomatic replacement deposit with lead and copper.

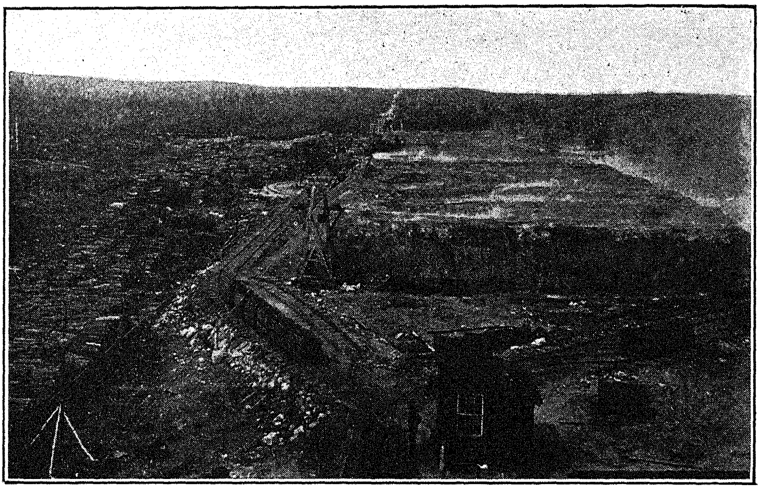

FIG. 120.—Roast yards near Victoria mine, Mond Nickel Company, Sudbury district, Ontario. (*After A. E. Barlow, Canadian Geological Survey.*)

The famous Temiskaming mining district in Ontario was discovered in 1903. The sulphides and arsenides of nickel and cobalt were all formed through solutions from heated waters associated with the basic intrusives of post-Middle-Huronian age. The native silver of Cobalt and Gowganda was the last mineral to form from solution in the ore bodies for it cuts the smaltite and the gangue mineral calcite. According to W. G. Miller these deposits are analogous to those of Annaberg, Saxony, and Joachimsthal, Bohemia. The ores may represent a leaching of the accompanying basic eruptive rocks, or they may have been

brought up from below. At all events they are not primary segregations.

Morenosite, the sulphate of nickel, and zaratite, the carbonate of nickel, are formed by the oxidation and carbonation of the sulphides and other ores of the metal.

The hydrous silicates of nickel, which are rarely, if ever, definite mineral species, but rather a mixture of the silicates of nickel with magnesium compounds and free silica, are entirely unlike the sulphides and arsenides in their genesis. They form a distinct class of ores. They are associated with masses of serpentine or other hydromagnesian rocks. They represent a concentration of the nickel in a peridotite magma, but especially one rich in nickeliferous olivine.

Character of the Ore Bodies.—Millerite occurs as an incrustation upon other minerals and as capillary crystals in cavities among quartz crystals. The nickeliferous pyrrhotite occurs as a contact deposit between quartzite and norite; also in irregular masses of large dimensions. The sulphides and arsenides appear in well-defined fissure veins traversing the basic intrusives and their adjacent terranes. Garnierite and genthite, together with other hydrous silicates of nickel occur in enormous deposits which in part result from precipitation and in part from the transition of a peridotite magma to serpentine.

The deposit near Noumea, the capital of New Caledonia, is perhaps the most noted nickel-bearing ore body in the world. The ores are particularly free from sulphur, arsenic and copper, three constituents injurious to nickel. There are two distinct varieties of these hydrous silicates present. The one is green and the other is chocolate brown. The green variety carries from 45 to 48 per cent. of nickel oxide; the brown variety carries from 43 to 46 per cent. of the oxide of nickel. Both contain small quantities of cobalt. The green variety was long mistaken for the green hydrous carbonate of copper, malachite. The brown variety was thrown away as worthless earth which was supposed to be colored by the hydrated oxides of iron. The green variety is now regarded as deposited from solution from above, while the brown variety tells its tale of the transition of the country rock peridotite to serpentine.

The method of mining at Noumea is simply open cut work. The ore is taken out in benches having faces about 30 ft. high so that the appearance of the quarry is not unlike the risers and

treads of a stairway. The ores are blended to a shipping grade, and sent to the lowlands on aerial rope ways, conveyed to the coast by ground trams, transferred to lighters, and then conveyed to ships. The quantity of ore seems to be inexhaustible. The ores are shipped to England, France, Holland, Germany and Australia.

Geographical Distribution of Nickel.—There are three distinct belts of nickel-bearing ores in the United States: (1) The Appalachian district; (2) the Central district; and (3) The Cordilleran section.

(1) *Appalachian belt:* But little nickel has ever been produced in this section. The largest deposit is in Lancaster County, Pennsylvania, where the nickeliferous pyrrhotite is associated with the altered intrusive, amphibolite, encased in mica schist. J. F. Kemp regards the amphibolite as an altered gabbro or norite, and the deposit as originally magmatic.

In the southern Appalachian belt in Webster County, North Carolina, the hydrous silicates of nickel appear in connection with the transition of a peridotite magma (dunite) to serpentine. The olivine of the original peridotite bears nickel. The nickel ore occurs in small fissures with talc and gymnite.

(2) *Central district* (*Mo.*) comprises the Mine La Motte, Fredericktown district, which furnishes annually a small amount of nickel as a by-product from the lead industry. Nickel was mined and smelted to a small extent by the North American Lead Company.

(3) *Cordilleran section:* This section embraces Arizona, Idaho, Oregon, Washington, and Wyoming, each of which have from time to time reported the existence of nickel-bearing minerals, but none have ore bodies that have yet assumed the dimensions of commercial importance. The most noted of these occurrences are those of Nickel Mountain, Oregon. According to H. Ries the ore is genthite associated with a quartz gangue. It occurs as a flat-lying deposit on the surface of a post-Cretaceous, pre-Eocene peridotite, or as veinlets in the peridotite and resulting serpentine. It is thought that the genthite represents an alteration product of the peridotite, for nickel has been found in the fresh peridotite.

Other Districts.—At Sudbury, Ontario, is by far the largest, the best known and the most important nickel-bearing ore body in America. From this nickeliferous pyrrhotite comes nearly all

of the nickel consumed in the United States. In fact, practically the entire production is said to be imported into the United States. However a small balance goes to England. New Caledonia, as elsewhere noted, is the largest single producer of nickel-bearing minerals in the world (Fig. 121). Nickel also occurs at Revda, southwest of Ekaterinburg, in the Urals nickeliferous minerals in connection with antigorite serpentine which is associated with metamorphic limestones and mica schists; also at Frankenstein, in Prussian Silesia, in association also with serpentine.

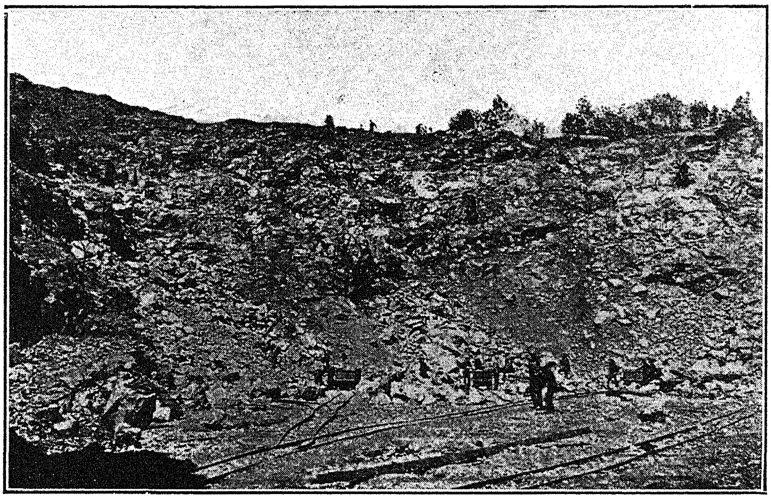

FIG. 121.—Main pit Creighton mine, Sudbury district, Ontario. (*After A. E. Barlow, Canadian Geological Survey.*)

The association of the nickeliferous minerals points to one thing of especial interest. Their home is everywhere shown to be connected with the ultrabasic and basic intrusives as peridotite, norite, diabase and diorite, rather than with the acidic magmas.

Geological Horizon.—The important ore deposits of nickel are in the older geological formations ranging from the pre-Cambrian to the Ordovician. The deposits in Oregon appear to be an exception for they are associated with the post-Cretaceous, pre-Eocene peridotite.

Methods of Extraction.—The ore is first roasted, then smelted to a Bessemer matte containing from 77 to 80 per cent. of the combined metals, copper and nickel, which is shipped direct to the United States and Great Britian for subsequent refinement by the electrolytic method. Plants exist for the treatment of the Canadian ores at Copper Cliff, Deloro, and Thorold, Ontario.

Uses of Nickel.—One of the earliest uses of nickel was in the manufacture of German silver, an alloy of nickel, copper and zinc. Nickel has been extensively used in coinage both in the United States and in foreign countries. The standard coin is said to consist of one part of nickel and three parts of copper. Nickel is used extensively in electroplating.

Nickel when welded upon iron and rolled into sheets is used for culinary utensils and many other objects. Nickel is used for making nickel steel for heavy machinery and engines; plates, turrets, and propeller shafts; for stamp mill shoes, crusher jaws, and bicycles. The bicycle and the motocycle have been in some measure responsible for the demand for nickel in recent years. An alloy consisting of 20 parts of nickel and 80 parts of copper is used as the casing of bullets for small bore guns, especially in foreign countries. Europe uses large quantities of nickel for that purpose. Nickeloid is a nickel-plated sheet of zinc which is non-corrodible and which is largely used in the manufacture of bath tubs, refrigerator linings and wherever a metallic surface is continuously exposed to moist air or water. Nickel aluminum alloys are of commercial significance. They possess a tensile strength exceeding 40,000 lb. to the square inch. New-silver is an alloy of nickel and aluminum containing 26 per cent. of nickel. It is susceptible of a high polish and as its name implies so closely resembles silver that it cannot readily be distinguished from the white metal. Minckin is a nickel-aluminum alloy containing more nickel, and widely used on account of its resistance to to the corrosive action of both acids and alkalis. Ferro-nickel contains 25, 35, 50, and 75 per cent. of nickel respectively, and is manufactured in large quantities so that the per cent. of nickel required in steel may be absolutely controlled. The alloy is malleable, homogeneous, and may be either rolled into plates or drawn into wires.

Chrome-nickel is utilized in the manufacture of armor plates and armor-piercing projectiles which are superior to the Harveyized steel armor plates once widely utilized. Tungsten-nickel is

used largely in the manufacture of cutlery. Molybdenum-nickel has many industrial applications and consists of varying quantities of the two metals. As molybdenum is fusible with difficulty and hard to alloy with steel, it is first alloyed with nickel, then the nickel alloy is alloyed with steel and used in the manufacture of forgings, foundry facings, gun shells, wires, and boiler plates. Monel metal contains 69 parts of nickel, 29 parts of copper and two parts of iron. Its tensile strength varies from 85,000 to 95,000 lb. to the square inch. The metal may be spun, forged, worked either hot or cold, and manufactured into boiler tubes and sheet metal suitable for casings where strength and non-corrodibility are desired. The specific gravity of monel metal is from 8.94 to 8.95. The metal possess 25 per cent. greater tensile strength and 50 per cent. greater elastic limit than steel. Therefore the mechanical possibilities of the alloy are almost endless. One of the most satisfactory uses of the metal is in seamless tubes for condensers and boilers for automobiles and motor boats. The high elastic limit of the metal coupled with its non-corrodibility are of special value in light machinery. The largest casing yet made of the metal is said to be the hub of a steamer propeller. This casting is 9 1/2 ft. in diameter and weighs 6500 lb. The propellers for hydroplanes are manufactured from monel metal.

Economics.—A few tons of nickel are produced annually as a by-product in the treatment of the lead ores at Mine La Motte, Missouri. There are two companies operating in the United States for the production of the metal. The International Nickel Company, Bayonne, New Jersey, and the American Nickel Works, Camden, New Jersey. The United States still continues to draw its supply of nickel from America's most noted locality, Sudbury, Ontario.

In 1909 a new nickel area was exploited in the Township of Dundonald on the west of the Temiskaming and Northern Ontario Railway. The ore is a Nickeliferous pyrrhotite closely resembling that of Sudbury, Ontario.

Manganese: Its Properties, Occurrence and Uses

Properties.—Manganese, symbol Mn, is a hard, brittle, steel-gray metal which oxidizes rapidly on exposure to moist atmosphere. It is readily soluble in hydrochloric acid. The metal does not occur free and uncombined in nature, and the refined

product has no commercial significance save in its alloys. Its specific gravity is 8, melting point, 1245° C, and its atomic weight is 54.93.

Ores of Manganese.—Manganese never occurs native on account of its remarkable affinity for oxygen. The element is widely distributed in nature in somewhat limited quantity. The oxides and the hydrous oxides are far the most important minerals.

Alabandite, MnS, 63.1 per cent. Mn. The only sulphide of the metals with an olive green streak.

Pyrolusite, MnO_2, 63.2 per cent. Mn. In pulverulent form known as the black oxide of manganese.

Polianite, MnO_2, 63.2 per cent. Mn. Distinguished from pyrolusite by its superior hardness and tetragonal crystallization.

Manganosite, MnO, 74.4 per cent. Mn.

Pyrochroite, $Mn(OH)_2$. The corresponding iron compounds are unknown in nature.

Manganite, Mn_2O_3, H_2O, 62.4 per cent. Mn.

Braunite, $3Mn_2O_3$, $MnSiO_3$, 69.68 per cent. Mn.

Hausmannite, Mn_3O_4, 72 per cent. Mn. The iron equivalent is magnetite.

Psilomelane, H_4MnO_5, 45 to 60 per cent. Mn. With barium and potassium variable.

Wad. The formula and percentage of manganese varies widely.

Rhodochrosite, $MnCO_3$, 61.7 per cent. MnO.

Rhodonite, $MnSiO_3$, 54.1 per cent. MnO.

The last two minerals are pink or rose colored and capable of some industrial application for decorative interior work.

Origin of the Ores.—Alabandite occurs in Colorado in association with the carbonate of manganese and the sulphide of silver, lead and iron. The action of alkaline sulphides upon the soluble salts of manganese in alkaline solution will effect its precipitation. The mineral is too rare to be of great commercial significance. It is used to a small extent in the metallurgy of the metal.

The numerous oxides and the hydrous oxides of manganese are all of secondary origin. Forschammer and Dieulafait report manganese in solution in oceanic waters. According to E. Maumené it occurs in the ashes of *fucus serratus*. According to F. W. Clarke manganese as an oxide or hydroxide exists in all deep-sea

deposits. It appears as grains in the clay or ooze, sometimes as a coating upon pumice, coral, shells, or fragments of bones, often in the form of nodular concretions made up of concentric layers about some other substance as a nucleus. Even in shallow waters, as in Loch Fyne, in Scotland, these nodules have been found, but they seem to be more characteristic of the deeper ocean abysses, whence the dredge often brings them up in great numbers.

Some doubt still exists as to the origin of these manganese nodules. C. W. Gumbel ascribes them to submarine springs holding manganese in solution, which is precipitated on contact with sea water. J. B. Boussingault considers that the manganese was derived from carbonates carried in solution by oceanic waters. According to L. Dieulafait the oxidation of the carbonates takes

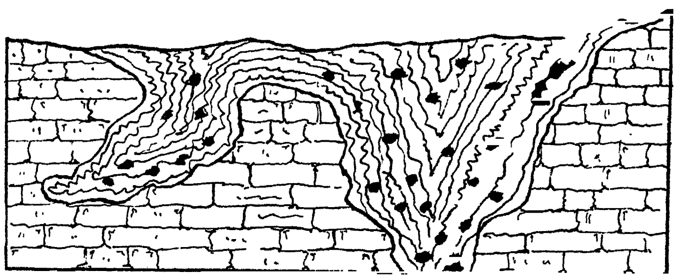

FIG. 122.—Section in the manganese region of north Arkansas, showing the formation of manganiferous clay by the decay of the St. Clair limestone. (*After Penrose.*)

place at the surface through atmospheric contact after which the precipitated oxide falls to the bottom of the sea. According to J. Murray the manganese is derived, like the well-known red clay, from the subaqueous decomposition of volcanic debris.

According to F. W. Clarke the manganese is derived from rock fragments as it is by weathering on the land. It goes into solution as a carbonate, is oxidized by the dissolved oxygen of the sea water, and precipitated near its point of derivation around any nuclei that may happen to be at hand. These nodules occur in close association with altered volcanic materials, and most abundantly in connection with the red clay of similar origin. Their impurities are those which this method of formation would lead one to expect (Fig. 122).

Manganese is almost invariably present in small quantities in

the crystalline rocks. (See Fig. 123.) It passes into solution as a carbonate or a sulphate to be redeposited as a carbonate, oxide, or hydroxide under varying conditions and in a variety of forms. The dioxide, hydrous or anhydrous is very common and is often seen in dendritic infiltrations so abundant in the sericite schists of Newbury, Vermont, and elsewhere. It is sometimes observed as a black coating on river pebbles and on the various rocks surrounding manganiferous mineral springs. M. Thresh cites small hard black nodules closely resembling seeds in the bowlder clays of Essex, England. Similar bodies have been found by W. M. Doherty on the surface of the ground in Australia.

The dioxides, pyrolusite and polianite, together with psilomelane are the most important ores in the metallurgy of manganese. The two former minerals have no analogue among the compounds of iron while the latter is a colloidal complex closely resembling

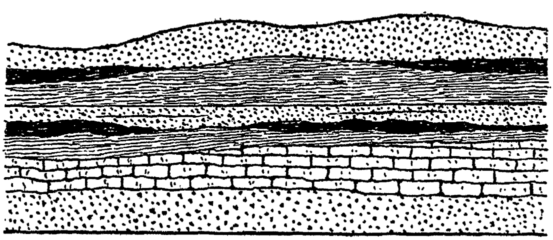

FIG. 123.—Lens-shaped masses of manganese ores interbedded with sedimentary rocks.

some of the sedimentary ores of iron. F. R. Mallet has observed pyrolusite and psilomelane as an integral portion in some of the Indian laterites. O. A. Derby regards the manganese ores of Queluz, Brazil, as residual deposits derived from rocks in which the manganese garnet was the most constant and characteristic silicate.

Wad, or bog manganese, is dissolved from the various rocks in the same manner as bog iron and redeposited under similar conditions. Bog manganese usually, if not always, bears varying quantities of iron and bog iron quite frequently carries manganese.

Character of the Ore Bodies.—In the United States the manganese ores occur in lenticular masses, stringers, pockets, grains and nodules (Fig. 124). The Brazilian ores most nearly correspond to a bedded deposit.

H. Ries makes a four-fold division of the manganese ores as

follows: (1) Manganese ores. (2) Manganiferous iron ores. (3) Manganiferous silver ores. (4) Manganiferous zinc residuum. The manganese ores proper comprise the high-grade pyrolusite and polianite that are reasonably free from iron. The Brazilian ore, psilomelane, meets this demand as will be seen later in the discussion of its composition.

The manganiferous iron ores consist largely of limonite and hematite bearing certain quantites of pyrolusite, psilomelane, or even wad. The higher grade ores of this class find use in the

FIG. 124.—Section exposed in a pit in the Dobbins mine in Georgia. The black bands represent manganese ore and the shaded portion clays. (*After Penrose.*)

manufacture of ferromanganese and spiegeleisen for the manufacture of steel.

The manganiferous silver ore consists of manganese and iron oxides bearing a sufficient amount of silver to pay for its profitable extraction. Gold is sometimes present in these ores and not infrequently the carbonate of lead. The ores in this class that are the richest in silver and lead are used for the extraction of these two metals. The iron and manganese content sometimes assures a higher price because of their fluxing properties. If the silver and lead content is too low to pay for the profitable extraction of these metals but rich in their iron and manganese content they

are utilized directly in the manufacture of ferromanganese and spiegeleisen. If the percentage of silver, lead, manganese and iron are too low to pay for the profitable extraction of any one of these metals the ores are sold directly as a flux and the lead and silver content reclaimed as a by-product.

The manganese zinc residuum is derived from the treatment of the manganiferous and zinciferous ores of Franklin Furnace, New Jersey. It consists largely of the oxides of manganese and iron which remain after the zinc has been converted into its oxide, ZnO. Zincite, willemite, franklinite and rhodochrosite are the common minerals. Rhodochrosite is also found as a gangue mineral at Rico, Colorado, and Butte, Montana.

Geographical Distribution.—Manganese minerals exist in all deep-sea deposits, in many shallow-water deposits, and in terrestrial deposits. There are four distinct belts of manganese minerals in the United States: (1) The Appalachian belt; (2) the Central district; (3) the Cordilleran section; and (4) the Pacific Coast belt.

(1) *Appalachian belt:* This belt stretches in a northeasterly direction from Alabama on the south to Nova Scotia on the north. The ores result from the decomposition of Cambro-Ordovician limestones and shales and appear largely as nodular masses in the residual clay.

Two localities in Georgia are important. They are Cartersville and Cave Spring. In the former district the ores are found in the residual clays derived from the decomposition of the Beaver limestone and the Weisner quartzite, and in the latter field the manganese deposits occur only in the clays that overlie the Knox dolomite. R. A. F. Penrose attributed the source of the manganese to the underlying Cambro-Silurian crystalline rocks. T. L. Watson, however, considers that the crystalline terranes to the east and the south furnished the ores, for no appreciable amount of manganese is found in the parent rocks from which the clays were derived. In any event the manganese was dissolved from the older rocks as a carbonate or sulphate and deposited from circulating solutions in the residual clays.

According to H. Ries there are two localities also for manganese minerals in Virginia, the James River valley in the Piedmont region and the Appalachian area. In the former field the ores occur in the residual clays and sands that have been derived from their associated crystalline terranes. Nodular masses sometimes

weighing 500 lb. have been obtained. These nodules are scattered through a yellowish-brown clay that form a nearly vertical layer between a decomposed granite and the residual material derived from a quartzose mica schist.

The more important deposits of the Appalachian Valley area occur in a series of irregularly distributed materials along the west foot of the Blue Ridge mountains for a distance of about 150 miles. The manganese ores occur in pockets in the clays of residual or sedimentary character along the contact of the Lower Cambrian quartzites with the overlying formations.

There are many scattered occurrences of manganese ores along the Appalachian belt in the more northern portion of the area. Those in the western part of Vermont at Brandon, are the most important and these have from time to time been mined. The ore is psilomelane. Both pyrolusite and braunite are found in Brandon, Bennington and Plymouth. Rhodonite occurs in Topsham, Vermont, near the village of Waits River in masses of sufficient size to be of considerable commercial value for decorative interior work, but the value of the material was largely destroyed through prospecting for chalcopyrite in the 60's.

(2) *Central District.*—The most important manganese deposits of the central belt are found in the neighborhood of Batesville, Arkansas. The ores are derived from the decomposition of the Ordovician, Silurian, and Carboniferous limestones. The lower deposits, perhaps enriched by the leaching of the Silurian ores, are the most important because of their higher manganese content and their greater freedom from phosphorus.

(3) *Cordilleran Section.*—Alabandite occurs on Snake River, Colorado, along with rhodochrosite, argentite, and galenite. The manganese silver minerals occur at Leadville, Colorado. In Utah the oxides of manganese occur in the residual deposits from the Triassic limestones.

(4) *Pacific Coast Belt.*—Two localities in California contain manganese deposits. The first of these consists of pyrolusite and psilomelane which occur in veins in Calaveras formations of Carboniferous age in Plumas County and elsewhere in the Sierra Nevada Mountains. The second field lies along the coast, both to the north and to the south of San Francisco. The ores appear as thin lenses, interbedded with the jaspers of the Franciscan formations of Jura-Trias age. At the Ladd mine the ore bodies are found as cavity fillings, infiltrations, replace-

ment deposits, and as veins and breccia cement in a fault fissure in jasper.

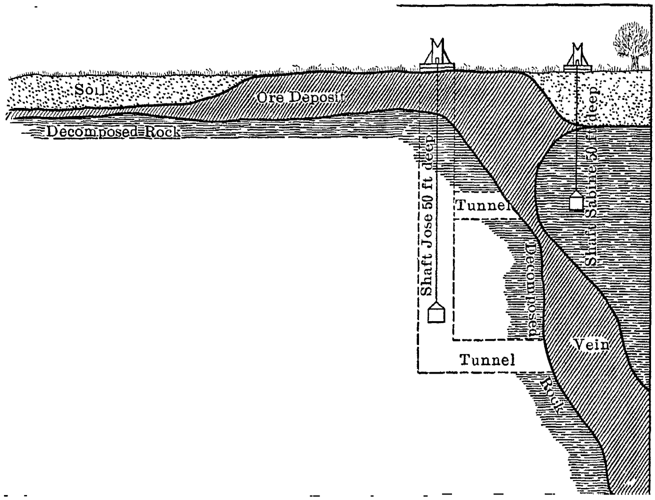

FIG. 125.—The manganese deposits at Pedras Pretas, near Bahia, Brazil, as shown by shafts and pits.

In Cuba, near Santiago, pyrolusite, manganite, braunite and wad occur as replacement deposits with jaspers. Perhaps the Brazilian deposits are the most noted ore bodies of manganese in

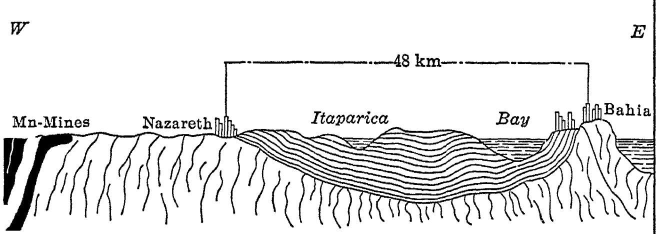

FIG. 126.—Section across the Cretaceous basin of Bahia, Brazil, showing the geologic position of manganese deposits.

the world. (See Figs. 125 and 126). The ore is from 25 to 30 ft. in thickness and thins out toward the edges producing large lens-

shaped masses that somewhat resemble bedded deposits. A single lump of ore weighing over 3000 lb. has been obtained. The cost of labor and railway transportation is $4.95 per ton. The price of the ore as determined by the Illinois Steel Company of South

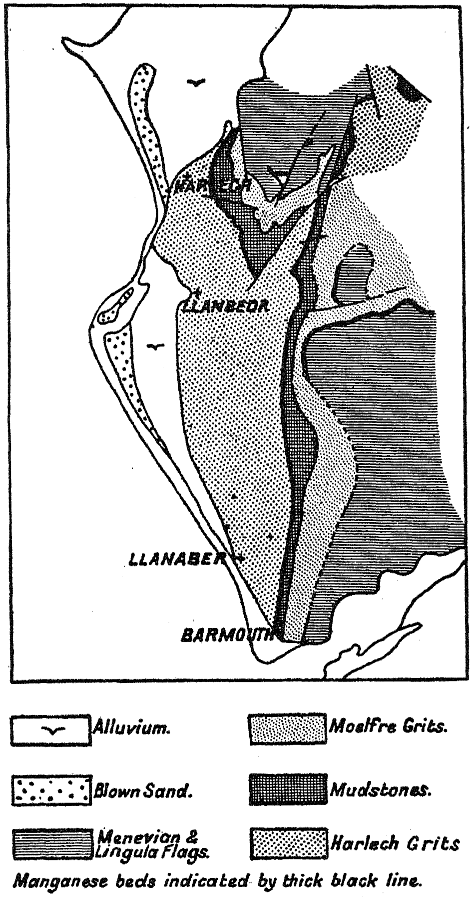

FIG. 127.—Map showing the manganese bearing horizons in the Cambrian rocks of Merionethshire, North Wales. (*After J. G. Goodchild.*)

Chicago, and the Carnegie Steel Company of Bessemer, Pennsylvania, ranges from $9 to $10 per ton. Therefore the approximate profit is $5 per ton. Fifteen cents per ton is deducted for each per cent. of silica exceeding 8 per cent. The Brazilian ore contains 1.05 per cent. of silica. Two cents per unit is deducted for

each 0.02 per cent. in excess of 0.2 per cent. of phosphorus. The Brazilian ore carries only 0.03 per cent. of phosphorus. The ore dried at 212° at Chicago allows 12 per cent. of iron and remaining moisture. The Brazilian ore carries but 7.6 per cent. of iron and water combined. The tenor of manganese required is 40 per cent., while the ore carries 54.8 per cent. manganese. The ore, therefore, is destined to make Brazil one of the principal competitors in the world's markets, and to supply quite largely the manganese ores for the United States. The Michigan and Wisconsin ores carry 8 per cent. of manganese. The residues of Franklin Furnace, New Jersey, carry from 14 to 25 per cent. of manganese. The Vermont ores carry from 30 to 50 per cent. of manganese. The Arkansas ores contain from 40 to 50 per cent. manganese. Therefore none of the American ores are so rich in their manganese content as the Brazilian deposits of the metal. These lower grade ores are best adapted for the manufacture of brick, glass and chemicals.

India and Russia also possess enormous deposits of manganese ore.

Geological Horizon.—The ores of manganese are not confined to any particular geological horizon. (See Fig. 127.) They appear in the Appalachian belt in the Cambro-Silurian formations. In Arkansas the formations bearing manganese range from the Ordovician to the Carboniferous. In the Harz Mountains the ores are Lower Permian. In California some of the deposits are as late as the Jura-Trias. In fact, bog manganese is in the process of formation to-day in the same manner and through the same agencies as bog iron ores.

Methods of Extraction.—Metallic manganese may be manufactured by the action of metallic sodium upon the chlorides of the metal, or by the Goldschmidt process. In this process the ores of manganese are converted into their oxides by roasting. The oxides are treated with aluminum at a high temperature when the oxide of aluminum, Al_2O_3, is formed and the manganese is reduced to the elemental state. The process depends upon the fact that aluminum has a greater affinity for oxygen than manganese.

Uses of Manganese.—Before the advent of the Christian era, manganese was used to color porcelain violet, purple, brown and black. A small amount of manganese imparts a violet color, and an excess of manganese produces a jet black. This black

color is often seen in door knobs. Intermediate amounts produce the purple and brown colors. The intensity of heat also effects the color. The oxide acts as a decolorizer in ordinary glass, and therefore corrects the green color imparted by iron.

Manganese ores are used largely in the manufacture of chlorine for the chlorination of gold. In the manufacture of bromine where the ore acts as a carrier of oxygen. Manganese ores are used in the manufacture of oxygen from potassium chlorate where the black oxide of manganese plays the part of a catalytic agent. Manganese ores are also used in the manufacture of disinfectants. Here it serves as an oxidizing agent. They are also used as a gas purifier in the place of bog iron. Manganese ores are quite largely used in the disposal of municipal sewage, for manganese ore becomes an important oxidizer with the application of heat.

They are also used in the manufacture of potassium permanganate and the various salts of the metal for the chemical trade. They are also used as a flux in silver-lead smelting, and in voltaic batteries as a strong negative electrode. Manganese ores are used as a drier in varnishes, as a coloring agent in calico printing, in the manufacture of pottery, brick and many paints.

Nine-tenths of all metallic manganese is used in the manufacture of steel and in the alloys of the metal. In the manufacture of steel two manganese alloys are employed. The one is spiegeleisen, with less than 25 per cent. of manganese and with a general average of 20 per cent. manganese. The other is ferromanganese, with more than 25 per cent. of manganese and a general average of 80 per cent. manganese. The general ratio of spiegeleisen to ferromanganese is 1:4. The effect produced upon steel is intricate and very important. (1) It prevents the formation of gas cavities during the solidification of the steel. (2) It restores the necessary carbon to the steel. (3) It removes oxygen from the iron in the steel and (4) it imparts great hardness and toughness to the steel. A superior quality of toughness is imparted by less than 3 per cent. of manganese. With from 3 to 20 per cent of manganese the steel is particularly well adapted for many purposes where great abrasion is encountered, as in mine car wheels; in milling and crushing machinery; in coupling-pins; in car rails for curves, switches, freight yards and wherever heavy traffic is common.

One of the newest uses for manganese lies in the manufacture

of safes, where the results are extremely satisfactory. The body of the safe is cast in one solid piece. The door which is also of manganese steel is grooved and fitted into the doorway so accurately that the joint is perfectly tight and explosive liquids are not successfully forced into the safe. The ordinary files and chisels are useless in finishing the safe, therefore air-driven abrasive wheels are employed. The groove fits so perfectly that all attempts to open the safe by burglars' tools and high-grade explosives have thus far failed.

In a classification of the uses by means of the purity of the ores the following division may be made. (1) The very low-grade ores are used in the chemical trade, in the manufacture of glass, brick and pottery. (2) The high-grade ores are used in the manufacture of spiegeleisen and ferromanganese.

Manganese is also used in the manufacture of manganese bronze, which consists of manganese and copper with or without iron. It is furthermore utilized in silver bronze, which consists of manganese and copper, together with silver, aluminum and zinc. It is also used in the manufacture of titanium alloys. Many of the complex alloys of which manganese steel is a constituent are capable of wide industrial application.

In spite of the numerous uses of manganese ores, and the wide application of manganese steel, the production of manganese in the United States is comparatively small. The most important eastern locality is Virginia. Most of the manganese for domestic consumption is imported from Brazil. Cuba entered the race for the first time in 1900. It is therefore to be expected that Cuba will continue to be an important contributor of high-grade manganese ores for the market of the United States.

Zinc; Its Properties, Occurrence and Uses

Properties.—Zinc, symbol Zn, is a bluish-white crystalline metal. At a temperature of 100° it becomes soft, and at 150° it is ductile and malleable. It can therefore be readily rolled into sheets or drawn into wire. The sheets and wires do not become brittle again upon returning to the normal temperature. At a temperature of 300° C., zinc can be rendered pulverulent. The metal tarnishes readily in moist atmosphere, becoming coated with a basic carbonate of the metal. In dry atmosphere at the ordinary temperature it remains permanent. Ordinary

commercial zinc is readily soluble in the mineral acids. It burns in an atmosphere of oxygen with a bluish flame to zinc oxide. Its specific gravity is 7.1; melting point 419° C., boiling point, 918°, and its atomic weight is 65.37.

Ores of the Metal.—*Native Zinc,* Zn, 100 per cent. Zn. This metal has been reported from eastern Alabama and from near Melbourne, Australia, but the occurrences are not completely authenticated.

Sphalerite, ZnS, 67 per cent. Zn. Often with resinous luster. (Isometric).

Wurtzite, ZnS, 67 per cent. Zn. Many massive blendes are mixtures of these two minerals. (Hexagonal.)

Smithsonite, $ZnCO_3$, 51.96 per cent. Zn. When earthy and impure it is called dry bone by American miners.

Hydrozincite, $2ZnCO_3,Zn(OH)_2$, 60 per cent. Zn.

Zincite, ZnO, 80.3 per cent. Zn. Deep red to orange yellow.

Franklinite, $(Fe,Mn,Zn)O,(Fe,Mn)_2O_3$. A spinel of variable composition.

Voltzite, 4ZnS,ZnO. A rather rare oxysulphide of zinc.

Goslarite, $ZnSO_4,7H_2O$, 28.2 per cent. ZnO.

Calamine, $ZnSiO_3,Zn(OH)_2$, 54.2 per cent. Zn.

Willemite, Zn_2SiO_4, 58.5 per cent. Zn.

Origin of the Ores.—Zinc is fairly common but not widely diffused in nature. Dieulafait reports its occurrence in sea water. It has also been found in the ashes of sea weeds. The occurrence of native zinc in northeastern Alabama, in Shasta County, California, and near Melbourne, Australia, need confirmation. If native zinc occurs in these localities it is probably a reduction product.

The sulphide of zinc is by far the most important source of the metal. It is known as sphalerite, blende, or black-jack when crystallized in the isometric system, and as wurtzite when in the hexagonal system. The massive blendes are mechanical mixtures of these two minerals. The sulphide of zinc is precipitated in the laboratory by the action of ammonium sulphide upon the soluble salts of zinc, or by the action of hydrogen sulphide upon an alkaline solution of the metal. According to H. de Senermont, sphalerite is formed when zinc solutions are heated in a sealed tube in an atmosphere of hydrogen sulphide. According to F. W. Clarke, sphalerite is formed in nature at relatively low temperatures and at the higher temperatures it is

transformed into wurtzite. An ore body, therefore, containing wurtzite is probably a product of high temperatures. What these temperatures are and at what temperature the transformation of sphalerite to wurtzite takes place remain to be determined. Sphalerite has been produced by the action of decaying wood upon the solutions of zinc sulphate in old zinc mines. According to H. A. Wheeler, the massive blendes occur at North St. Louis, Missouri, embedded in lignite, where these blendes have evidently been formed by the action of organic matter upon soluble zinc compounds. C. R. Keyes reports sphalerite crystals on iron nails that have been immersed in mine waters for 15 years. W. P. Jenney cites the occurrence of sphalerite upon the walls of a tunnel that has been closed and filled with mine waters for several years. Crystals of sphalerite have also been observed upon the pick marks in abandoned zinc mines. Sphalerite in its association with the lead mines of the Mississippi Valley appears to be of secondary origin.

According to J. D. Robertson, zinc sulphide occurs at Galena, Kansas, as a white mud mingled with acid water. Evidently the zinc was brought into solution by the oxidation of sphalerite and thrown out of solution either by the action of sulphureted waters or by organic matter.

Smithsonite is a secondary mineral of metasomatic origin. Wherever zinciferous solutions percolate through limestones a reaction follows with the deposition of the zinc as smithsonite in the place of the removed calcium compounds. G. Bischoff reports several instances in which smithsonite has formed as a deposit from natural waters. The alteration of the zinc ores in Missouri and Arkansas has given rise to a zinciferous clay known as tallow clay.

Zincite and franklinite at Franklin Furnace, New Jersey, form a unique deposit produced by contact metamorphism. This ore deposit will be discussed in detail a little later in this chapter.

Goslarite is an oxygenated secondary mineral. It occurs as a solid in the Rammelsberg mine near Goslar in the Harz Mountains, at Schemnitz in Hungary, and elsewhere. It is formed through the oxidation of sphalerite. It is present in solution in mine waters and zinciferous mineral springs. It is in this form that zinc is leached out of zinciferous rocks and transported elsewhere for subsequent deposition as an ore body.

Willemite, which has come into prominence through the study

of the emanations of radium, is often a product of contact metamorphism.

Character of the Ore Bodies.—Zinc ores occur in nature under a great variety of conditions, which may be classified as follows: (1) As true metalliferous veins. (2) As cavity fillings not of true-fissure vein type. (3) As irregular masses in the metamorphic rocks. (4) As irregular masses, or disseminations, formed by replacement or impregnation in limestones and quartzites. (5) As contact metamorphic deposits. (6) In residual clays.

The associated minerals are galenite, pyrite, marcasite, and, less frequently, chalcopyrite, together with calcite, dolomite, fluorite and barite as gangue minerals. In the zone of weathering in zinciferous ore bodies the sulphides are altered to smithsonite, hydrozincite or calamine. The oxidized ore often yields more readily to metallurgical treatment than the sulphide ores, and even though the percentage of zinc may be lower they may be of greater value than the unoxidized ores.

Where zinc and lead occur together as sulphides the zinc disintegrates more rapidly than the lead and its sulphate solutions are transferred downward for the enrichment of the ore bodies at the lower levels.

Geographical Distribution.—The zinc ores of the United States are located in three distinct belts as follows: (1) The Appalachian belt; (2) the Central belt, and (3) the Cordilleran section.

(1) *Appalachian Belt.*—There are several scattered occurrences of zinc ores in this belt. Some of these produce small quantities of lead, as in Tennessee and southwestern Virginia. The ores are associated with the Cambro-Ordovician limestones. The unoxidized ores consist of sphalerite, galenite, pyrite, and belong to the disseminated replacement-breccia, type. The oxidized ores, which are concentrated in the residual clays in close proximity to the weathered surface of the limestones, consist of smithsonite, cerussite and calamine.

In Pennsylvania, in the Saucon Valley, an ore body of zinc occurs that at one time bid fair to be of considerable commercial significance but the ore body has never been extensively worked. In Thetford, Vermont, sphalerite and galenite occur in a fissure vein with a quartz gangue in the Vershire schists.

The most important ore body of zinc in this belt occurs at Franklin Furnace, N. J. According to A. C. Spencer, two large bodies of zinciferous ore, different in character from any other

known ore deposit, occur at Mine Hill, near Franklin Furnace, and at Sterling Hill, near Ogdensburg. The ores consist of varying proportions of franklinite, zincite and willemite admixed with calcite, and in some instances with the silicates rhodonite, garnet and tephroite. In some parts of the vein franklinite is the only important mineral present. In some instances it is accompanied by willemite; in others only by zincite, and some cases by both minerals. Occasionally the ore consists of zincite set in a matrix of coarsely crystallized calcite.

At Mine Hill the zinc content ranges from 23 to 29 per cent. The iron ranges from 19 to 22.5 per cent. The manganese from 6 to 12 per cent. The zinc content of the Sterling Hill ore is somewhat less than the per cent. given above. The ore at Mine Hill comprises a layer varying in thickness from 12 to 100 ft. or even more, bent upon itself to form a long trough with sides of unequal height. The outcrop of the ore is about 2,600 ft. in length.

A. C. Spencer regards the Sterling Hill deposits also as comprising a trough. The layer ranges in thickness from 10 to 30 ft. In some parts of the layer the ore consists largely of franklinite and in others of zincite. The sides of the trough are of unequal height and strike in a northeasterly direction. The dip of the veins range from 45 to 60 degrees.

According to A. C. Spencer, the deposits must have been introduced either before or during the metamorphism of the containing limestones and the igneous rocks which are now gneisses. He regards the main ore body at both Sterling Hill and Mine Hill as injected bodily into the limestones like igneous intrusions, and the leaner ores of Sterling Hill as deposited by magmatic waters which permeated and replaced the associated limestones. According to J. F. Kemp, the ore was deposited from solutions stimulated by granitic intrusions subsequently metamorphosed into gneisses. According to J. E. Wolff, the ores are contemporaneous in form and structure with the enclosing limestones, and therefore older than the granites.

(2) *Central States.*—In the Central belt the Joplin district is the most important producer of zinc. In fact it is one of the most important zinc-mining camps of the world. The geological section consists of Mississippian cherts and limestones overlaid with Pennsylvanian limestones, shales, sandstones, with occasional beds of coal. All these terranes are of Carboniferous age.

According to E. T. Hancock, the ore deposits fall into two groups: First, runs and their modifications; and second, blanket veins, or sheet ground deposits. The runs are irregular, usually elongated, sometimes tabular and inclined bodies of ore uniformly associated with disturbed strata which are brecciated, slickensided and faulted. The runs are generally a few hundred feet

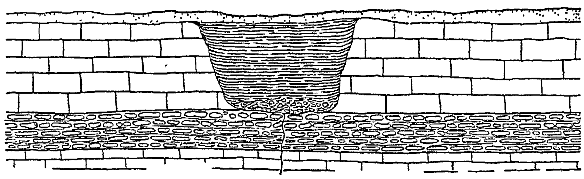

FIG. 128.—Depression in the limestone extending down to the Grand Falls chert member, filled with Cherokee shale, Joplin, Missouri, (*After W. S. Tangier-Smith and C. E. Siebenthal, U. S. Geological Survey.*)

in length but the Arkansas run exceeds 1000 ft. The runs also have an average width of about 50 ft. and a maximum width of 300 ft. The roughly elliptical closed runs constitute one of the most distinctive and constantly recurring types of ore bodies in the Joplin District.

The blanket veins are nearly horizontal, tabular ore bodies extending parallel with the bedding planes of the limestones and

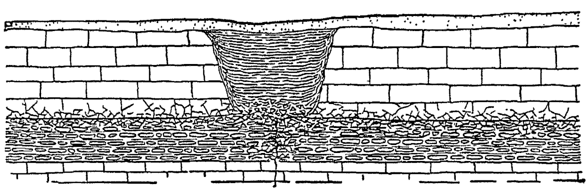

FIG. 129.—Depression in the limestone extending down to the Grand Falls chert member, filled with shale and compressed. Joplin, Missouri. (*After U. S. Tangier-Smith* and *C. E. Siebenthal, U. S. Geological Survey.*)

cherts. The typical sheet ground appears to be developed invariably in the Grand Falls chert.

In the vertical distribution of the ores the sulphide of lead is the most abundant in the upper portions of the ore deposits and the sulphide of zinc in the lower portions. This distinction, however, is not universal. The most profitable mining is confined to the

Boone limestones that overlie the base of the Grand Falls chert (Figs. 128 and 129).

Concerning the genesis of the ore bodies, W. S. Tangier-Smith says:

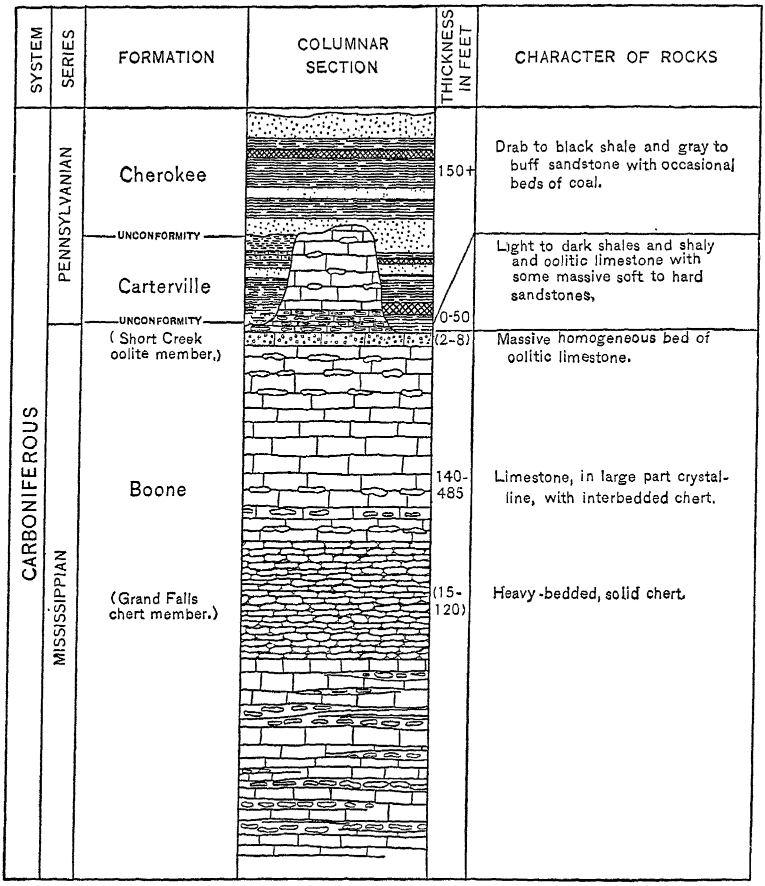

Fig. 130.—Generalized geologic section of the Joplin, Missouri district. (*By permission of the Macmillan Company, from Ries' Economic Geology.*)

"The common association of the lead and zinc ores with the limestones, the known occurrence of these metals in sea water, their probable precipitation in minute quantities in limestones laid down in these waters; the actual wide-spread occurrence of lead and zinc in very small amount in the limestones of the Mississippi Valley, both Carboniferous and Cambro-Ordovician, together with the general course of circulation

reaching the Joplin district is through the lead and zinc-bearing calcareous formations, render it reasonably certain that these formations are the source of the ore bodies."

The immediate source of the ores is the various limestones situated below the Pennsylvanian terranes.

The method of mining at Joplin is peculiar to that district alone. The land holder leases the property for ten years for a royalty of 8 per cent. to 15 per cent. of the gross value of the output. The leasee prospects by drilling and sinking shafts, by

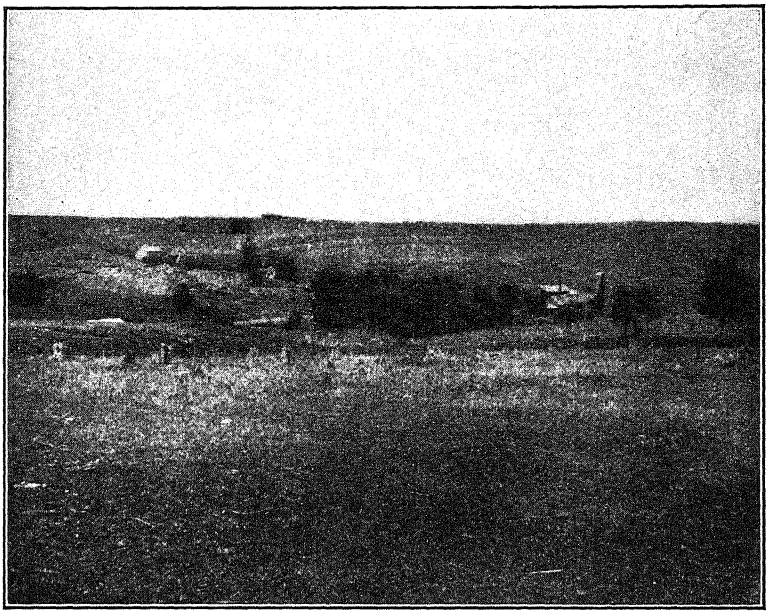

FIG. 131.—View near Linden in Wisconsin lead and zinc district. (*By permission of the Macmillan Company, from Ries' Economic Geology.*)

cross cutting and drifting, and then subleases for a royalty of from 15 per cent. to 25 per cent. of the gross output of the ores. Three results are said to have followed this method. 1. The discovery of many new ore bodies. 2. Freedom from serious labor troubles. 3. Increase in the annual output of zinc, so that the Joplin district has become the premier area of the world (Fig. 130). Other important districts are located in Wisconsin, Arkansas, Kentucky and Illinois. (See Fig. 131.)

3. *Cordilleran Region.*—In the Cordilleran district the best rep-

resentative is found in Colorado. This belt possesses argentiferous zinc sulphide with sufficient lead and iron to render the ore undesirable for the manufacture of zinc. In 1899 Wales and Belgium entered the market and bought largely of the Colorado ores. Favorable freight rates were obtained by way of Galveston, Texas, to Swansea and Antwerp, viz., $10 per ton. The value placed at the mine was $3 per ton. Although the commodity purchased by Wales and Belgium was a zinc concentrate, it was removed as a by-product which enhanced the value of the remainder of the products, thereby leading to a more profitable development of the zinc resources of the state. There is now in operation a zinc smelter at Pueblo, Colorado, and a zinc oxide plant at Canyon City, Colorado.

In Cumberland and Derbyshire, England, sphalerite with some smithsonite occurs in the Carboniferous limestones. Here, as at Joplin, Missouri, the sulphide of zinc is far more abundant in the lower portions of the ore body than the sulphide of lead. In both localities smithsonite is fairly abundant and occurs as a true metasomatic deposit due to the reaction of zinciferous solutions upon the associated limestones. On the island of Sardinia, metasomatic zinc ores occur at the junction of limestones with non-calcareous beds, which contact may represent either a fault line or a plane of normal sedimentation. Many of the Sardinia deposits below the zone of weathering carry the characteristic zinc sulphides as their permanent ore. The Grecian ore to the southwest of Athens consists largely of the sulphides of lead and zinc, associated with siderite. Thomas and MacAlister consider the zinciferous solution of hydrothermal origin. As they came up from below they passed through small fissures in the associated shales without depositing their metallic content. The presence of the calcareous material caused a deposition of the ores at the junction of the limestones with interbedded shales.

In Upper Silesia the ores of zinc occur in Triassic limestone and dolomite interbedded with mottled sandstones. In the Picos de Europa district in the Province of Asturias, Spain, the zinciferous ores are associated with limestones of Carboniferous age, and of Cretaceous age in the Santander district.

Geological Horizon.—The ores of zinc do not seem to be confined to any particular geological horizon. Those of the Appalachian belt as already noted are Cambro-Ordovician. On the island of Sardinia they belong to the same age. At Joplin,

Missouri, and Cumberland, England, they are Carboniferous. The Westphalian ores lie often in the Devonian limestones, while in the Alpine district, in Carinthia, the zinciferous ores are most abundant in the Triassic limestones.

Methods of Extraction.—(1) *The Calcination Process.*—The sulphide ore is first calcined to liberate the sulphur and convert the metal into its oxide according to the following equation: $ZnS+3O=ZnO+SO_2$. If the ore is the carbonate it is also calcined to drive off the carbonic acid present according to the equation, $ZnCO_3=ZnO+CO_2$. If the ore is the oxide it may also be calcined to drive off any sulphur that may be present or liberate any other volatile constitutents. The oxide obtained by calcination is dissolved in dilute mineral acid, precipitated as a

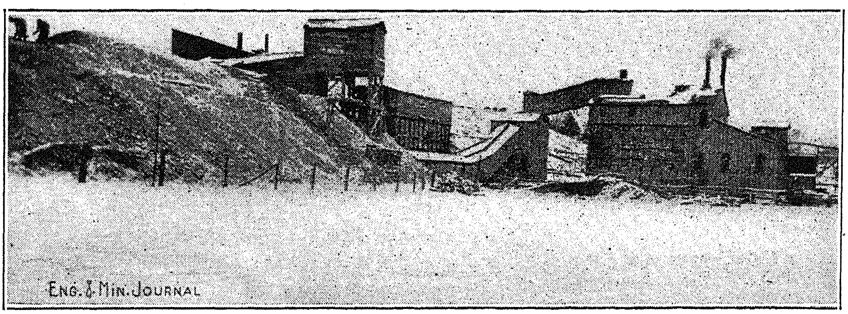

FIG. 132.—Zinc mine and mill of the Northern Ore Company, Edwards, New York.

carbonate, and converted into its oxide, which is finally reduced to the elemental state with charcoal obtained from sugar (Fig. 132).

(2) *The Electrolytic Process.*—According to Ashcroft and Swinburne, good results are obtained by this process and a large interest is attached to the method which is especially applicable to the sulphides of zinc.

(3) *Fusing with Calcium Carbide.*—In some localities the sulphides of zinc are fused with calcium carbide and from the resulting product several useful metals, as copper, etc., are easily obtained.

(4) *Distillation.*—At Iola, Kansas, a considerable amount of zinciferous ores have been treated with natural gas as a fuel. The standard furnace distills 25,000 lb. of ore with 45 per cent. of

coke or poor coal as a reducing agent. Unfortunately the supply of natural gas at Iola is becoming exhausted.

Uses of Zinc.—Zinc enters the marts of trade in the form of rolled sheets, and also in cast cakes 1 in. in thickness. In the latter form it is known as spelter. Spelter cakes are extremely brittle and break with a crystalline fracture. If the metal is pure, the crystal faces are large and present a smooth or perfect cleavage. If small quantities of iron are present, dull spots appear on the crystal face, and with only a small percentage of iron present, the spelter breaks with granular fracture. Spelter is seldom, if ever, pure. Particular notice should be given to iron in spelter. The iron does not distill with the zinc. It comes from the apparatus used in the distillation, and the stirring rods utilized in the process of cooling.

Zinc is intimately associated with both the iron and the copper industries. Galvanized iron is used in wire nettings, corrugated roofing, water tanks, etc. Galvanized iron is not produced by electrolytic deposition as the name implies, but by dipping the iron in a bath of molten zinc. The coating of zinc preserves the iron from rusting. It is far better able to withstand the corrosive action of moist air and water than ordinary tinned iron. The film of zinc is heavier than the corresponding film of tin, therefore the protuberances of the sheet iron are more perfectly protected.

Zinc is used in a large number of useful alloys, especially with copper. English brass consists of 1 part of zinc and 2 parts of copper. Dutch brass, consists of 10 parts of zinc and 5 parts of copper. Muntz metal of 1 part of zinc and 3 parts of copper. Some varieties of bronze, 1 part of zinc, 4 parts of tin, and 95 parts of copper.

With copper, tin, and antimony, zinc will mix in all proportions. With lead and bismuth the alloys of zinc are of definite proportions. The presence of zinc increases both the hardness and the durability of the alloy.

Zinc is used in the desilverization of lead, also as a precipitant for gold from potassium cyanide solutions. The form used may be sheet zinc, zinc scraps, granulated zinc, or zinc dust. The last form is more widely used than any of the others because it presents a larger surface to the action of the cyanide solutions. Three grains of gold per ton of solution may yield a profit. One-half pound of zinc will completely reduce to the elemental state all the gold in a ton of these dilute solutions.

Zinc is used in the manufacture of zinc oxide, or zinc white, which is now extensively used as a pigment in the place of white lead. It is manufactured by burning metallic zinc in an atmosphere of oxygen or in a current of air. It does not equal white lead in covering power or body, but it is vastly superior to white lead wherever the walls of the building are exposed to the action of hydrogen sulphide, as in chemical or mineralogical laboratories, and in cities and towns where large quantities of coal are consumed.

Zinc is used also in the manufacture of zinc salts for the chemical trade. Perhaps the most important salt of zinc is the chloride. It is used to a limited extent in dentistry for spongy gums. It is utilized extensively in preserving railroad ties. The tie is immersed in a solution of zinc chloride, and after becoming thoroughly saturated, the life of the tie is much prolonged. This new use is increasing rapidly with many of the larger railroads.

Zinc is used also in electrolysis and in the manufacture of white vitriol. It is used in the manufacture of lithopone, a pigment consisting of barite, zinc oxide, and zinc sulphate. The industry is carried on to a considerable extent by the New Jersey Zinc Company and by the Grasselli Chemical Company. White vitriol is largely consumed in the manufacture of glue and special paints.

The most important commercial and technical change in the zinc industry in recent years appears in the predominance which the natural gas smelters of Kansas have gained over those depending upon coal for a fuel. The Joplin ores were formally treated at LaSalle and Peru, Illinois, St. Louis, Missouri, and Pittsburg, Kansas. The first two were smelting centers long before the history of zinc began at Joplin. The last is only 26 miles from Joplin and owes its development to the local coal production. The use of natural gas has resulted in closing down the coal smelters and the installation of gas smelters.

CHAPTER IX

THE RARE METALS

MOLYBDENUN, TUNGSTEN, TITANIUM, ZIRCONIUM, VANADIUM, URANIUM, COLUMBIUM, TANTALIUM, SELENIUM, TELLURIUM

Molybdenum

Properties.—Molybdenum, symbol Mo, is one of the rarer metals. Its specific gravity is 8.6, and its atomic weight 96.

Mode of Occurrence.—Molybdenum is a member of the same elementary group with chromium, but its geological affinities are widely different. It occurs as a primary constituent of the acid rocks, like granite, rather than the basic rocks like peridotite, the home of chromite. The metal does not occur free in nature and is not widely diffused.

Ores of Molybdenum.—The sulphide of the metal, molybdenite, MoS_2, is the most important ore. This mineral closely resembles graphite, but may be easily distinguished from it. Graphite is quickly copper-plated when in contact with a strip of zinc in a solution of $CuSO_4$; molybdenite is slowly copper-plated under the same conditions. Graphite is unaffected by HNO_3; but molybdenite is oxidized to MoO_3. The molybdates of several metals are well known as natural minerals: *Wulfenite*, $PbMoO_4$; *powellite*, $CaMoO_4$; *pateraite*, $CoMoO_4$; *belonesite*, $MgMoO_4$; and *molybdic ocher*, $Fe_2(MoO_4)_3,7\frac{1}{2}H_2O$. The oxide of molybdenum occurs as a secondary mineral, molybdite, MoO_3.

Origin of Ores.—Molybdenite, the most important source of the metal, is of primary origin. According to G. O. Smith, it occurs at Cooper, Maine, as an impregnation deposit. It occurs in the pegmatite dikes and their associated granites. The oxides and ocher are always of secondary origin.

Character of Ore Bodies.—A. R. Crook has observed large masses of molybdenite in quartz veins in granite at Crown Point, Washington. The author has observed molybdenite on the eastern coast of Newfoundland in large quartz veins traversing sandstones and conglomerates. In Maine it occurs in pegmatite

dikes and the adjacent granites. In Canada it is often associated with granites, and also appears in veins cutting limestone. J. W. Wells has observed molybdenite in pyroxenite, as though produced by contact metamorphism.

Geographical Distribution.—Molybdenum ores are found in small quantities in the northern Appalachian belt; in the Cordilleras, especially in Utah; in the Pacific Coast belt, in California and Washington; in Canada and Newfoundland.

Geological Horizon.—The ores seem to be more abundant in the pre-Cambrian, Cambrian and Ordovician terranes, but the Devonian granites sometimes carry molybdenite.

Method of Reduction.—Molybdenum may be reduced to the elemental state by the action of nascent hydrogen upon the oxide or chloride.

Uses.—Molybdenum is used in the manufacture of several important alloys, and in tool steel. It renders steel hard and tough. It is used in the manufacture of chemical salts, the most important of which is ammonium molybdate, used largely to determine the presence of phosphorus in iron ores and in steel. Molybdenum is used as a fire-proofing material, as a germicide, and as a disinfectant. Sodium molybdate is used to color pottery and porcelain blue, and to dye silks and woolens. Molybdenum tannate is used to color leather, and molybdenum indigo to color india-rubber.

The production of molybdenum in the United States is small. Ordinary years furnish about 50 tons of molybdenite, containing 92 per cent. of the sulphide, MoS_2.

Tungsten

Properties.—Tungsten, symbol W, is one of the acid-forming heavy metals. It is closely allied with molybdenum, and is in the same elementary group with chromium. Its melting point is 1700° C.; its specific gravity is 19.1, and its atomic weight is 184.

Ores of Tungsten.—The ores of tungsten are not numerous. They are mostly tungstates of the metals. The tungstate of calcium, scheelite, and tungstite, the oxide, are important.

Wolframite, $(Fe,Mn)WO_4$, is the most important among the tungstates of the metals; *Hübnerite*, $MnWO_4$, is a tungstate of manganese; *reinite*, $FeWO_4$; *stolzite*, $PbWO_4$; *cuprotungstite*, $CuWO_4$; *scheelite*, $CaWO_4$, and *tungstite*, WO_3.

Origin of the Ores.—Wolframite is both a primary and a secondary mineral. In the Cornish tin mines, wolframite is a companion of cassiterite, the most important ore of tin. The two minerals may appear as primary segregations. While tungsten is an annoying impurity, a by-product is obtained which is used in the manufacture of the sodium tungstate of commerce. According to J. D. Irving, wolframite occurs with cassiterite in the Etta tin district of the Black Hills, South Dakota. Primary wolframite has been observed in quartz veins cutting granite; and secondary wolframite in associated limestones, apparently formed by metasomatic replacement. At Oscola, Nevada, the tungstate of manganese is abundant in veins of quartz cutting a porphyritic granite. Scheelite, the tungstate of calcium, is also present in the same veins. Hübnerite occurs with scheelite and wolframite in similar veins in the Dragoon Mountains, Arizona. At Trumbull, Conn., the ores are wolframite, scheelite and tungstite. At Longhill, Conn., scheelite occurs along the contact of limestones with hornblende gneiss and diorite. Scheelite occurs in the Province of Quebec in quartz veins cutting slates and sandstones. Its association is with the acid intrusives, as granites and pegmatites, rather than the ultra-basic rocks, as peridotite.

Character of the Ore Bodies.—Tungsten minerals occur as masses (lens-shaped) in the early segregation of an acid magma; in veins cutting acid intrusives; in limestones, by metasomatic replacement; and as contact deposits between limestones and their intrusives.

Geographical Distribution.—There are three belts of tungsten minerals in the United States: the New England, the Cordilleran, and the Western belt.

Geological Horizon.—The ores seem to be confined to the acid intrusives of the older geological formations.

Method of Extraction.—The metal is most easily extracted from scheelite, the tungstate of calcium.

Uses.—The largest and the most important use of tungsten is in the manufacture of tool steel. It imparts both hardness and toughness to the steel. It is this use which renders the mining of tungsten minerals profitable. According to F. L. Hess:

"The introduction of tungsten into steel gives it the property of holding a temper at a much higher temperature than high-carbon steels. When lathe tools are made from tungsten steel, the lathes may be speeded up until the chips leaving the tool are so hot that they turn blue."

The percentage of tungsten in tool steel varies with the manufacturers. Some use from $1\frac{1}{2}$ to $3\frac{1}{2}$ per cent.; others from 16 to 20 per cent. of tungsten. According to C. A. Edwards, the hardest steel recorded contained 19.37 per cent. tungsten. Tungsten is added to steel in the form of an alloy of tungsten and iron carrying from 40 to 82 per cent. of the former metal. Alloys of tungsten with copper and aluminum are well known, and of considerable technical value. A small quantity of tungsten added to aluminum greatly improves its resistance to erosion, and increases its tensile strength. Tungsten is used in the manufacture of crucibles for electric furnaces. Powdered tungsten is mixed with carbonaceous matter in the form of a paste, pressed into the desired shape, and sintered. Tungsten is used as a filament in incandescent electric lamps. The extreme whiteness of the light renders it far superior to that of the carbon incandescent lamp, which it is rapidly supplanting. It is far more efficient than the tantalum lamp. The drawback is the brittleness of the filament, and much material is lost in shipment. The advantages are its whiterlight, its longer life, and its use in either alternating or direct currents. Metallic tungsten has been used in arc-lamp electrodes. Tungsten is used in rendering curtains, draperies and papers fire-proof. It is used as a mordant in dyeing, also in weighting delicate fabrics. As sodium tungstate has approximately the same ratio of expansion for moderate temperatures as platinum, it is used for sealing platinum apparatus for making water determinations in rock analysis. Tungsten is used as a pigment in the manufacture of glass, also of gold and violet bronze powders. Calcium tungstate is used as a screen to make X-rays visible.

Economics.—The production of tungsten is so closely related to that of pig iron, from which tungsten steel is manufactured, that the output for 1908 was far below that of 1907. The value of its production is as follows: 1905, \$268,676; 1906, \$348,867; 1907, \$890,048; 1908, \$229,995; 1909, \$559,900; 1910, \$844,526, and 1911, \$407,985; 1912, \$492,000.

Titanium

Properties.—Titanium, symbol Ti, is a rare metal, extremely difficult to isolate in a pure state, owing to the fact that it unites directly with nitrogen, forming a nitride. Its melting point is

3,000° C.; its specific gravity is 3.543, and its atomic weight is 48.1.

Mode of Occurrence.—Titanium is often catalogued as one of the rarer elements; yet it is almost invariably present in the igneous rocks, and in the sedimentaries derived from them. According to F. W. Clarke, out of 800 igneous rocks analyzed in the laboratory of the U. S. Geological Survey, 784 contained titanium. It is found in nature only in the oxidized state (Fig. 133).

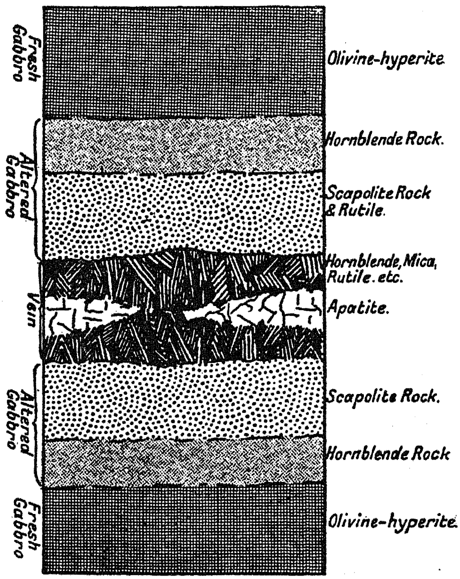

FIG. 133.—Titaniferous apatite vein in gabbro. (*After J. H. L. Vogt.*)

Ores of Titanium.—Ilmenite, FeO, TiO_2, is a faintly magnetic iron-black mineral, with a black or brownish-red streak. Several varieties have been recognized, based on the relation of the iron to the titanium. The true ilmenite carries from 26 to 30 per cent. of titanium. *Menaccanite* carries from 20 to 25 per cent. of titanium.

Leucoxane is a metamorphic decomposition-product of ilmenite and its numerous varieties. It occurs as a white or reddish mineral surrounding ilmenite.

Rutile, TiO_2, shades in color from reddish-brown to black. It occurs in tetragonal crystals, often twinned.

Nigrine, TiO_2, is a black variety, containing from 2 to 3 per cent. of Fe_2O_3.

Ilmenorutile is a black variety from the Ilmen Mountains, containing 10 per cent. or more of Fe_2O_3. It carries too much iron to be classified as rutile, and too much titanium for ilmenite.

Octahedrite, TiO_2, occurs in definite octahedrons of the tetragonal system.

Brookite, TiO_2, crystallizes in the orthorhombic system.

Perovskite, CaO,TiO_2, is a calcium titanate.

Titanite, CaO,TiO_2,SiO_2, often called sphene, on account of its wedge-shaped crystals.

The oxide, Ti_2O_3, has not been observed as an independent mineral.

Origin of the Ores.—Ilmenite is widely diffused throughout both the acid and the basic intrusives, and on account of its basicity is one of the earliest minerals to segregate from a cooling magma. Leucoxane is always secondary in origin. Rutile is a common constituent of the acid intrusives, and is occasionally found in limestones, dolomites and slates. The variety octahedrite is always of secondary origin. Perovskite is associated with both eruptive and metamorphic rocks. Titanite is a pyrogenic mineral in the older secretions of the acid intrusives, as granites, syenites, etc.

Character of the Ore Bodies.—The titaniferous iron ores occur in considerable quantities in the State of New York. They are mined chiefly for their iron content, and occur in more or less lens-shaped masses. Titaniferous magnetite is a common mineral in New York and New England. In Nelson County, Va., large dikes of pegmatite, sometimes hundreds of feet thick, cut a biotite gneiss. Rutile and ilmenite occur in these dikes, associated with the potassium and sodium feldspars, amphibole, hornblende, quartz and apatite. In the pegmatite itself, the titanium ores are not sufficiently abundant to become a commercial consideration; but the pegmatites are cut by veins or dikes of rutile, ilmenorutile, and apatite, which F. L. Hess considers as a later phase of the pegmatites. At Roseland, Virginia, in the same county, the rutile comprises about 4 per cent. of the pegmatite. The rock is crushed and concentrated together with the decomposition-products that overlie the pegmatite, to a product containing approximately 98 per cent. TiO_2.

Geographical Distribution.—There are three belts of titanium-bearing rocks in the United States: (1) The Appalachain belt. The maximum development occurs, as above noted, in Nelson Co., Virginia. In Chester, Pa., rutile occurs in exceptionally pure crystals, which have brought high prices for the dental trade and for museum specimens. It occurs in New York, where large quantities of titaniferous iron abound, and in Vermont, where many fine crystals of rutile have been obtained. (2) The Northern Belt, where titaniferous ores have been mined in Minnesota in considerable quantity. (3) In Wyoming, where the ore is similar to that found in Minnesota.

In foreign countries rutile is found in Norway, South Australia, and Queensland.

Geological Horizon.—Titanium minerals are more abundant with the pre-Cambrian, Cambrian, and Ordovician terranes than with the later geological formations.

Uses.—The most important use of titanium is in the manufacture of steel and cast-iron, to which it imparts hardness and toughness. The alloy ferro-titanium, containing 10 to 20 per cent. of titanium, is first manufactured. This is added to the molten iron so as to produce a steel bearing 0.1 per cent. titanium. Steel rails thus formed resist the wear of heavy traffic much longer than ordinary rails. Titanium-thermit is another form in which titanium is introduced into steel. Cupro-titanium is an alloy of titanium used in the manufacture of bronze and other castings containing copper. Titanium is used in the manufacture of electrodes for arc-lights. The chloride of titanium, $TiCl_2$, is used in dyeing. The sulphate, $Ti_2(SO_4)_3$, is used both as a striper and a mordant. The titanous potassium oxalate is used as a yellow dye and a mordant in the treatment of leather. $Ti(SO_4)_2$ is used in the detection of fluorine. The tile industry also utilizes rutile. It gives a soft, beautiful yellow color in tile and brick. Rutile is also used to give to artificial teeth an ivory tint. The nitride of titanium is sometimes formed in smelting titaniferous iron ores. This compound has commercial possibilities as a fertilizer. Rutile finds some use as a gem.

Zirconium

Properties.—Zirconium, symbol Zr, is a rare element closely allied to titanium. Its melting point is 1500° C; its specific gravity is 4.15, and its atomic weight is 90.6.

Ores of the Metal.—*Zircon*, $ZrSiO_4$, is the most important source of the element and its compounds. Unlike the other rare minerals to which it is allied, it occurs chiefly as a silicate widely diffused in the igneous rocks. It is easily distinguished from all other minerals by its crystal form; viz., that of a tetragonal prism terminated by a tetragonal pyramid at either extremity; by its color, which shades through brown and yellow to green; and by its hardness of 7.5.

Zircon is one of the least alterable of all minerals, for it contains no protoxides, and only the most insoluble of dioxides. It, however, passes into the hydrous state, producing amorphous and isotropic species or varieties. This is effected by the loss of silica, and the addition of iron oxides through infiltrating waters. Auerbachite, calyptolite, cryptolite, malacon, oerstedite, and tachyaphaltite are all altered varieties of zircon.

In some instances, zircon seems to have been of pneumatolytic origin. According to F. W. Clarke, it is one of the earliest minerals to crystallize from a cooling magma, and the first of all silicates to thus solidify. The varieties of zircon mentioned above are all of secondary origin, arising through the hydration and metamorphism of zircon.

Beccarite is an olive-green variety of zircon from Ceylon.

Braddeleyite, ZrO_2, is an oxide of zircon found in Brazil and Ceylon.

Geographical Distribution.—Zircon is one of the commonest constituents of all classes of igneous rocks. It is more abundant, however, in the acid than in the basic intrusives. It is especially abundant in the granites, pegmatites, syenites, gneisses, diorites and pyroxenites, and in the younger eruptives. The most noted American locality is in Burke, McDowell, Henderson, Polk and Rutherford Counties, N. C., where it occurs in the gold-bearing monazite sands, due to the disintegration of granite and gneissoid rocks. At Grenville, Canada, it occurs in a crystalline limestone, in association with wollastonite, titanite and graphite.

Geological Horizon.—Zircon is not restricted to any horizon, for it occurs in the igneous rocks of all ages.

Method of Extraction.—Zircon is separated from its matrix by rough crushing and washing. A clean separation can be made with electrical machinery and by careful washing. A small quantity of zircon is obtained as a by-product from the monazite concentrates.

Uses.—The metal is obtained in two forms, one amorphous, the other crystalline. The former burns readily in the air, the latter only at the high temperature of the oxyhydrogen flame. The oxide, ZrO_2, is the most important salt. It is reported to have been used in the tile and pottery industries. The demand for zircon is small. It has been supplied in the United States by the intermittent working of the mines near Zirconia, N. C. The crystals of Zircon are larger in Henderson County, where they occur in pegmatites, than elsewhere when associated with monazite. The crystals of zircon are larger also in the pegmatites than they are in the granitic, gneissoid, or hornblendic rocks.

Only a few hundred pounds of zircon are obtained during an entire year, and in some years there seems to be no recorded output of the mineral.

Vanadium

Properties.—Vanadium, symbol V, is a rare element closely allied to phosphorus. It acts both as an acid and a base. The metal is permanent at ordinary temperatures, but is rapidly oxidized to V_2O_5 when heated. Its melting point is 1680° C.; its specific gravity is 5.5, and its atomic weight is 51.2.

Ores of Vanadium.—*Vanadinite*, $3PbO$, V_2O_5, $PbCl_2$, is the most common vanadium mineral.

Descloizite, $4RO$, V_2O_5, H_2O. ($R = Pb$, Zn, in ratio 1 : 1.)

Cuprodescloizite, $4RO$, V_2O_5, H_2O. ($R = Pb$, Zn, Cu.)

Pucherite, Bi_2O_3, V_2O_5, is a vanadate of bismuth.

Mottramite is a vanadate of lead and copper.

Carnotite is a vanadate of uranium and potassium of some commercial significance where it occurs as canary yellow impregnations in the sandstones of western Colorado and eastern Utah.

Roscoelite is a vanadium silicate of the mica family, where vanadium occurs displacing aluminum. The color ranges from a clove-brown to a dark greenish-brown.

There are many rare minerals bearing small percentages of vanadium. These are most common in the ferromagnesian rocks. They are present in the titaniferous magnetites, and in rocks of nearly every class, whether of igneous or of sedimentary origin. Vanadium has been observed in bauxite, cryolite, rutile, peat, lignite, and in the ashes of wood.

Origin of Ores.—Small quantities of primary vanadium may occur in the segregation of titaniferous magnetites. Carnotite occurs as impregnation deposits in sandstones. It occurs also in the pegmatite veins of Radium Hill, South Australia. Where carnotite occurs on or near partially altered vegetable matter, organic substances have acted as precipitants for vanadium. Mottramite occurs as an impregnation deposit in England, where it has attained some commercial significance. Roscoelite is found sparingly in the gold veins of Boulder County, Colorado, and in Granite Creek, California, several pounds of roscoelite were wasted in the extraction of the included gold.

Geographical Distribution.—Workable deposits are chiefly confined to the Cordilleran belt. Colorado and Utah are the most promising; but vanadinite ores have been produced commercially in Arizona and New Mexico.

Geological Horizon.—Small quantities of vanadium may be found in the rocks of all ages; but the workable deposits of western Colorado and eastern Utah are in Jurassic and Cretaceous sandstones.

Uses.—Like titanium, vanadium finds its most important use in the manufacture of steel. Even small quantities of the metal impart a remarkable toughness to the steel. In the manufacture of steel it removes both oxygen and nitrogen, and forms carbides, with beneficent effect upon the finished product. Vanadium steel resists both shock and fatigue far better than ordinary steel. It is therefore well fitted for saws, springs, and mechanical tools in general. Vanadium is introduced into steel either as an alloy with chromium, or with manganese, or both. To these alloys nickel is sometimes added. Each metal present tends to make the resulting steel both hard and tough. Vanadium is also used in the manufacture of cast iron, brass and bronze.

When 3 to 5 parts per 1,000 are added to steel, vanadium communicates remarkable properties. It doubles the coefficient of resistance to fracture under all circumstances (as shock, crushing, elongation, etc), and at the same time imparts such extreme hardness as to make it possible to reduce the armor of vessels in thickness almost one-half. The reason that the effect of 0.5 or 0.3 per cent. of vanadium is so general and intense on steel lies in the extreme avidity vanadium has for oxygen. The presence of minute traces of the metal in a bath of molten steel would lead to an immediate and absolute reduction of every trace of iron oxide.

Now, the rupture of the best prepared steel is due to traces of the oxides of Fe,—even microlites of Fe_2O_3 act like the stroke of a diamond on the thickest glass. Vanadium steel acquires its maximum hardness not by tempering, but by annealing at 700° to 800° C. A planing machine with vanadium steel cutting edges can be set at work with the greatest velocity, and even when heated at red-heat, it still continues to take off shavings of iron or casting without exhibiting any signs of exhaustion. This property is of vital importance in projectiles. The shock they receive upon striking their mark raises them to a very high temperature, yet vanadium steel retains all its sharpness, and its penetrating force remains intact. Ordinary steel softens and loses its cutting power. Vanadium is destined to cause a revolution in armaments.

The salts of vanadium have considerable commercial significance. F. L. Hess states that metavanadic acid is used as a substitute for gold bronze in paint; that vanadium chloride is used as a mordant in printing fabrics; that vanadium trioxide is used as a mordant in dyeing; and that vanadium pentoxide is used as a reducing agent in the treatment of organic compounds in an acid bath. This anhydride is also used in the place of platinum in the contact process for the manufacture of H_2SO_4, and as a photographic developer. Vanadin is a medicinal preparation with potassium chlorate. Vanadium salts are also used as fertilizers, in coloring glass, and in the manufacture of a waterproof black ink.

Economics.—The price paid for vanadic acid in 1910 was about $2.50 per pound according to purity. The price paid for the alloy ferro-vanadium was about $5 per pound of vanadium content.

Uranium

Properties.—Uranium, symbol U, is a rare and heavy metal. Its melting point is 800° C; its specific gravity is 18.7, and its atomic weight is 238.5—the highest of all known elements.

Ores of the Metal.—*Uraninite*, xUO_2, yUO_3, with some PbO, and a little N. It crystallizes in isometric octahedrons, but usually occurs massive and granular. The color varies in shades of gray, green and black. In uraninite, helium was first discovered and later polonium. Both uranium and its compounds are

radioactive, and uranium itself may be the progenitor of its more highly active companion, radium. The mineral is remarkable in that it presents the only instance in which nitrogen has been found belonging to the original crust of the earth. Uranniobite is the crystallized variety of uraninite in which the element nitrogen occurs in its maximum percentage, 2.6 per cent.

Bröggerite, UO_2, UO_3, ThO_2, occurs in octahedral crystals.

Cleveite, UO_2,UO_3,ThO_2, Y_2O_3, the trioxide, UO_3, is present in larger percentage in cleveite than in the preceding minerals. It crystallizes in hexahedrons, often modified by other fundamental isometric forms.

Nivenite, UO_2, UO_3, ThO_2, Y_2O_3, occurs massive, velvet-black in color and is more soluble than the other varieties of uraninite.

Pitchblende, UO_2, UO_3, is massive uraninite. ThO_2 and the rare earths are absent, while nitrogen is sparingly present, if represented at all.

Coracite is an alteration product of uraninite in its transition to gummite.

Gummite, $(PbCa)U_3$, SiO_{12}, $6H_2O$, is an alteration product of uraninite which occurs in rounded or flattened pieces, closely resembling gum.

Carnotite is cited by H. Ries as occurring in Montrose County, Colo., and also in Utah. Carnotite is a vanadate of uranium and potassium which occurs in canary-yellow impregnations in sandstones in western Colorado and eastern Utah. It is second in importance of the uranium-bearing minerals.

There are several well known hydrous arsenates and phosphates of uranium and the alkaline earth metals, but they are not of commercial significance.

Origin of the Ores.—Most of the minerals bearing uranium are of secondary origin. The columbates and tantalates of iron containing uranium are primary constituents of pegmatites.

Character of Ore Bodies.—Uraninite is sometimes obtained from metalliferous veins, but more often it is found in association with acid intrusives, granites and pegmatites. In Colorado it is obtained from a schistose granite which in places gives way to porphyry. Uranium is chemically unlike vanadium, with which it is associated in one of its most important ores; viz., carnotite. Uranium has been found in coal; in an anthracitic mineral in a pegmatite vein in Canada; in anthracitic bitumen from Sweden; and in the ashes of seaweeds. Carnotite occurs as impregnation

deposits in sandstones. It occupies the interstices between the grains, and occurs in thin coatings in the cracks and crevices of the rocks. In some instances, lumps of several inches in thickness have been obtained. These lumps are very pure.

Geographical Distribution.—Uraninite and gamotite occur in Montrose County, Colorado, and also in Utah. Pitchblende is found in Gilpin County, Colo. Carnotite occurs in Montrose, San Miguel, Dolores, Rio Blanco, and Routt Counties, Colo., and in the eastern part of Utah.

Geological Horizon.—In southwestern Colorado, the carnotite deposits are in Jurassic sandstones, and in northwestern Colorado in Cretaceous sandstones.

Extraction of the Metal.—Uranium salts have been extracted at the Haynes plant near Cedar, Colo.; but the haul both for ore and supplies is long and expensive. The ore is of low grade, and the problem of commercial extraction is difficult.

Uses.—Uranium, unlike the other rare metals considered above in this chapter, does not find its most important use in the manufacture of steel. This use will be considered later.

Uranium minerals and their salts are radioactive. They have given rise to the study of radiology, and to a new method for the determination of the age of the earth through radium emanations. A careful study of the data published along this line places the age of the earth at approximately 100,000,000 years. A pocket-knife, keys, coins, or any piece of metal may be covered with uraninite and placed on a photographic plate in a dark room; and in a few days, upon the development of the plate, photographs of the objects will be obtained.

Uranium hardens and toughens steel, like its associate, vanadium. It is used in Germany in the manufacture of steel and ferro-alloys, and of gun-barrels.

The salts of uranium are used in the manufacture of pottery glazes and iridescent glass. The double acetate of uranium and sodium is used in the determination of phosphates. Uranyl acetate is used in medicine as a precipitant for proteids, and in the chemical laboratory in the volumetric determination of zinc. In this determination, the nitrate may be substituted for the acetate. The nitrate is also used in the manufacture of glazes; in photography; in the chemical laboratory in the determination of arsenic and phosphoric acid, and in the detection of morphine. The

trioxide is used to paint porcelain red, and is also used in calico printing.

Columbium

Properties.—Columbium, symbol Cb, is a rare acid-forming element, closely allied to tantalum. Its melting point is 1950° C, its specific gravity is 7.2, and its atomic weight is 93.5.

Ores of the Metal.—*Columbite,* FeO, Cb_2O_5, is a columbate of iron. It crystallizes in the orthorhombic system. Its color is brownish-black to black.

Manganocolumbite, MnO, Cb_2O_5, is a columbate of manganese, in which manganese has displaced the iron of normal columbite. Iron may be present in considerable quantity.

Samarskite, R''_2, R'''_3, $(CbTa)_6O_{21}$, where R'' = Fe, Ca, UO_2 and R''' = Ce, Y. The mineral is a rare columbate and tantalate of iron, calcium, uranium, and the rare earth metals.

Euxenite is a columbate and titanate of the rare earths. It is an altered samarskite.

Pyrochlore is a metacolumbate of calcium and cerium.

Fergusonite is a metacolumbate of Y, Er, Ce and U.

Sipylite is a columbate of erbium.

There are several other rare minerals of which columbium is a constituent.

Character of the Ore Bodies.—Columbite is a primary mineral, found in the acid intrusives, granites and pegmatites. In these veins single masses of columbite have been obtained weighing more than 2000 pounds.

Geographical Distribution.—Columbite is found sparingly in the Appalachian belt in North Carolina, Virginia, Pennsylvania, New York, New Hampshire, Connecticut and Maine. In Maine, columbite is associated with cassiterite. In New Hampshire, at Acworth, it is associated with beryl; in New York, at Greenfield, it is associated with chrysoberyl. The Appalachian belt is scarcely of commercial significance. Columbite occurs in Colorado near Canon City, and at the Etta mine in the Black Hills, South Dakota. The largest masses found in America occurred in the Etta mine in association with cassiterite.

Uses.—The interest attached to columbium at present is due to the incandescent lamp industry. There is little if any production of columbite other than for the tantalum present, and for museum and laboratory materials.

Tantalum

Properties.—Tantalum, symbol Ta, is an acid-forming element closely allied to columbium, with which it is generally associated. It is ductile, malleable, sectile, hard, tough, and readily withstands corrosion. Its melting point is 2250° C., its specific gravity is 10.4, and its atomic weight is 181.

Ores of the Metal.—*Tantalite,* FeO, Ta_2O_5, is a tantalate of iron. It occurs in orthorhombic crystals; is black with a cinnamon-brown streak. It is the most important source of the tantalum of commerce.

Manganotantalite, MnO, Ta_2O_5, is a tantalate of manganese, in which manganese has displaced the iron of normal tantalite to a considerable extent, if not entirely.

Ixiolite is a rare tantalate of tin.

Samarskite, mentioned under Columbium, is a rare mineral rich in tantalum. There are many tantalates of the rare earth metals known in mineralogy, but they are rare minerals.

Origin of the Ores.—Tantalite, like its associate, columbite, occurs as a primary mineral in the acid intrusives, as the granites and pegmatites. Some of the rare tantalates are decomposition-products of tantalite, and therefore of secondary origin.

Geographical Distribution.—Tantalite is found in practically the same localities as columbite. Massive tantalite has been found in Coosa County, Alabama; and manganotantalite of exceptional purity in western Australia. The American supply is mainly obtained from Scandinavia and Australia.

Separation.—The columbates may be separated from the tantalates by fusion with $HKSO_4$ or KOH, and treating the fused mass with HCl and metallic zinc. When diluted with an equal volume of water, a permanent and intense blue coloration is obtained. In the case of the tantalates thus treated, the blue color soon disappears.

Uses.—F. L. Hess states that the only practical use to which tantalum is put is in making filaments for incandescent electric lamps. More than twenty thousand 20-candle-power incandescent electric lamp filaments can be made from a single pound of tantalum. The tantalum lamps used in America are manufactured from imported tantalum. The cost of the metal is more than $300 per pound.

The metal is ductile, malleable, hard, tough, and strongly

resists corrosion. These properties ought to lead to new uses of commercial significance.

A small tonnage of tantalum-bearing minerals is produced by the Western Reduction Company of Omaha, Neb. The source of the ore was near Keystone, South Dakota.

Selenium

Properties.—Selenium is a non-metallic element closely allied to sulphur. Its association with copper, silver, lead, mercury, bismuth and thallium, together with its relation to tellurium, a semi-metallic element, has led to its consideration in this work on the metallics. Selenium is known in four allotropic modifications: (1) A brick-red amorphous powder; (2) a black crystalline powder; (3) in dark red translucent monoclinic crystals; and (4) a black, shining, brittle, amorphous mass. It is a conductor of electricity. The conductivity is twice as great in the presence of light as in the dark. The melting-point of selenium is 217; it boils at 680° C., and burns with a blue flame to SeO_2. Its specific gravity varies from 4.26 to 4.8, and its atomic weight is 79.2.

Ores of Selenium.—*Native selenium*, Se.

Selen-sulphur, SeS, an orange-red or reddish-brown mineral, consisting of mixtures of selenium and sulphur in unknown proportions.

Selen-tellurium, SeTe, a blackish-gray mineral with metallic luster, consisting of selenium and tellurium in the ratio of 2: 3.

Clausthalite, PbSe, a selenide of lead.

Naumannite, PbSe, $13Ag_2Se$. Another variety gives 5PbSe, Ag_2Se; a third variety is Ag_2Se, with 73.15 per cent. of Ag.

Guanajuatite, Bi_2Se_3, a selenide of bismuth.

Berzelianite, Cu_2Se, a selenide of copper.

Lehrbachite, $(PbHg_2)$ Se, a selenide of lead and mercury.

Eucairite, Cu_2Se, Ag_2Se, a selenide of copper and silver.

Crookesite, $(Cu, Ag, Tl)_2Se$, a selenide of copper, silver, and thallium.

Zorgite, a mixture of the selenides of silver, lead, and copper.

Origin of the Ores.—The majority of the selenides are primary minerals; only a few are of secondary origin. Native selenium may be a product of volcanic emanation, like its associate sulphur. Selen-sulphur occurs in crusts with sal-ammoniac on

the Vulcano and Lipari Islands, also at Kilauea in the Hawaiian Islands. Selen-tellurium occurs with a gangue of quartz and barite in the silver veins of El Plomo, Honduras. Zorgite occurs in argillaceous schist with galenite and various copper minerals in Thuringia.

Character of Ore Bodies.—Selenium minerals appear in metalliferous veins with the commoner gangue minerals, and as crusts from volcanic emanation.

Geographical Distribution.—Selenium minerals are rare and not widely distributed. In America they are largely confined to the Cordilleran section. Selenides appear in association with the gold ores of the Camp Bird mine near Ouray, Colorado; in the Tonopah gold ores, Nevada; near Marysville, Utah; and at Clear Lake, California; in the New Zealand gold fields; in Japan; and in the Lipari Islands.

Geological Horizon.—The selenium minerals are more abundant in the terranes associated with the later intrusives of the Cretaceous and Tertiary ages than in the older rocks.

Method of Extraction.—Pyrite containing small quantities of selenium is often used in the manufacture of H_2SO_4. In the roasting of the pyrite, the selenium is oxidized to SeO_2, and is carried off with the sulphur, which is oxidized to SO_2. The selenium dioxide is deposited as a solid partly in the flues and partly in the chambers. These deposits are gathered and boiled with dilute H_2SO_4 and HNO_3 or $KClO_3$ to oxidize the substance completely to H_2SeO_4. Strong HCl reduces the selenic acid to selenous acid, H_2SeO_3. Then SO_2 passed through the selenous acid precipitates the selenium as a red powder, and the SO_2 is oxidized to H_2SO_4.

Uses.—In the light, selenium is a good conductor of electricity, and on account of this peculiarity, it is used in a number of electrical devices. It has been used in telephoning along a ray of light, and in transmitting pictures, photographs, or even sounds to a considerable distance by means of a telephone or telegraph wire. It is used to light and extinguish gas-buoys automatically. This use is dependent upon the fact that selenium is a non-conductor of electricity in the dark and a good conductor in the light. Selenium is used also in measuring the quantity of Röntgen rays in therapeutiapc plications.

Economics.—The production of selenium from year to year is very small. It is sometimes recovered from the anode

slimes or mud where it is left with the gold, silver, etc., in the electrolytic refining of copper. The price per ounce is approximately $2.

Tellurium

Properties.—Tellurium, symbol Te, is a semi-metallic element, the least abundant of the sulphur group. It is brittle and possesses a metallic luster. The color is tin-white or bluish-white. It is a poor conductor of both heat and electricity. It burns with a blue flame to TeO_2, its melting point is 446° C., its hardness is 2.2; its specific gravity is 6.25, and its atomic weight is 127.5.

Ores of Tellurium.—*Native tellurium*, Te, often with traces of selenium and gold. It occurs in hexagonal crystals, also massive. *Selen-tellurium*, SeTe, with the ratio of tellurium to selenium nearly that of 2 to 3. *Stützite*, Ag_4Te, is a telluride of silver with metallic luster, containing 22.5 per cent. of Te and 75.5 per cent. of Ag.

Hessite, Ag_2Te, is another telluride of silver, with 36.7 per cent. of Te and 63.3 per cent. of Ag.

Petzite, $(AgAu)_2Te$, is a telluride of both silver and gold. If the ratio of the silver to the gold be 3 : 1, the analysis would give 32.5 per cent. Te, 42 per cent. Ag, and 25.5 per cent. Au.

Sylvanite, $(AuAg)Te_2$, is a telluride of gold and silver. With a ratio of 1 : 1, the analysis would give 62.1 per cent. Te, 24.5 per cent. Au, and 13.4 per cent. Ag.

Krennerite, Ag_2Te, Au_2Te_3, appears to be an admixture of the tellurides of gold and silver.

Calaverite, $AuTe_2$, is a telluride of gold, although a part of the gold is often displaced by silver. These tellurides appear in the nature of alloys rather than definite compounds, for both tellurium and the tellurides of gold serve as a precipitant for gold.

Altaite, PbTe, is a telluride of lead, with 37.7 per cent. Te and 62.3 per cent. Pb.

Coloradoite, HgTe, is a telluride of mercury, with 38.5 per cent. Te and 61.5 per cent. Hg.

Melonite, Ni_2Te_3, is a telluride of nickel, with 76.2 per cent. Te, and 23.8 per cent. Ni.

Rickardite, Cu_4Te_3, is the telluride of copper.

There are also three well-known tellurides of bismuth: *Tetradymite*, Bi_2Te_3; *Joseite*, Bi_2Te; *Wehrlite*, Bi_3Te_2, and a sulphotelluride of bismuth, *Grünlingite*, Bi_4TeS_3.

Tellurite, TeO_2, the dioxide, is an oxidation-product of tellurium.

There are complex tellurides and sulphotellurides of the precious metals that need not be mentioned here.

Origin of the Ores.—The most of the tellurium minerals are of primary origin. The oxide, the tellurates and the tellurites are alteration-products.

Character of the Ore Bodies.—The tellurides of the precious metals occur in large fissure-veins, often in pockets of immense richness. The intrusive granites are traversed by younger irruptives, with which the tellurides are connected. H. Ries states that they are not found in contact deposits. (Calaverite occurs as a coating on the walls of fissures at Cripple Creek, Colo.)

Geographical Distribution.—The tellurides of the metals in the United States are largely confined to the Cordilleran and Pacific Coast belts. Altaite has been found in Gaston County, North Carolina. The tellurides are found abundantly at the Red Cloud mine, Boulder County, Colorado; the Camp Bird and Torpedo-Eclipse mines in Ouray County; in many mines at Telluride and Cripple Creek, Colorado; and in the Stanislaus and Golden Rule mines in Calaveras County, California. The tellurides occur abundantly in western Australia.

Geological Horizon.—A little tellurium may be found in the mineral deposits of the older geological formations; but it is far more abundant in association with the Cretaceous and Tertiary formations of the west.

Uses.—The aluminum alloy, Al_2Te_3 is made by melting aluminum and throwing in from time to time small pieces of tellurium. When the powdered metals are heated together, they unite with great violence. The uses of the semi-metal tellurium are few.

Economics.—The output is small, like that of selenium. A small amount of tellurium may be obtained in the electrolytic refining of copper, where the tellurium is deposited in the anode slime or mud, with its associates, selenium, gold, and silver.

CHAPTER X

ECONOMICS

The statistical portion of this book has been left for the final chapter on economics. The author refrains from giving in detail the output of the different metals by states and countries, and would refer the reader for such data to the carefully compiled statistics in the *Mineral Resources of the United States* and in the *Mineral Industry*. The order followed in this chapter in the discussion of the economic conditions surrounding the different industries and the output of the different metals is the same as that given in the main body of the work.

GOLD

Production in the United States.—The output of gold in the United States during the present century has been fairly steady. A decrease of about $4,000,000 was suffered in 1903. A similar decrease was experienced in 1907. This was followed by a third decrease in 1910, and by a large decrease in 1912.

The banner year was reached in 1909 when the production was $99,673,400. This large production was due to several causes: (1) The tendency to increased production which began in 1907. (2) To a small degree to the closing of many mines in the base metal camps which curtailed the output of lead, copper and zinc, and increased the output of gold by the shifting of labor to the placer deposits. (3) The fundamental cause of the large prosperity in the gold mining industry is the fixed and limitless demand for the yellow metal.

According to H. D. McCasky of the U. S. Geological Survey, the output of gold for 1912 was $91,685,168. In 1911 it was $96,890,000. The decrease is ascribed mainly to Nevada where there was a falling off in the annual production of nearly $4,000,000, chiefly from Goldfield, but to a smaller degree also to Nation and Seven Troughs camps. The Goldfield mines produced a larger tonnage of ore, but of lower grade than in the

preceding year. The production was delayed at Seven Troughs by a cloudburst in July and the mill at National was burned in September. On the other hand there was an increased production in the Manhattan, Fairview, and Round Mountain districts.

In Colorado also there were several fluctuations in the gold mining camps. The San Juan district, which includes the counties of Dolores, La Plata, Ouray, San Juan, and San Miguel, showed a decrease of about $1,000,000. This came largely from the Camp Bird mine on Sneffels creek. The Cripple Creek district increased its output by nearly $400,000, due in part to the successful drainage by the Roosevelt tunnel. Montana, Utah and Washington each showed a decreased production.

The gold mining industry in South Dakota gave the largest output in the history of the state, the increase being about $400,000 over the output of 1911, due largely to activities in the Homestake mines. The large hydroelectric plant of the company owning these mines was completed and put into operation in 1912.

California retains the rank of the first producer which position she wrested from Colorado in 1911. Nevada, Alaska and South Dakota are also large producers.

Gold dredging was especially active in California and Alaska where increased dredging capacity was added. The 120 dredges in operation in 10 states including Alaska produced more than $10,000,000 of gold.

According to the Geological Survey, in 1911, the gold and silver mills produced 53.8 per cent. of the output, the placers 24 per cent., and the large smelting plants 22 per cent. Of the product from the gold and silver mills 26.1 per cent. was produced by cyanidation, 23.9 per cent. by amalgamation, and 3.8 per cent. by chlorination. Dredging alone gave 10.9 per cent.

During the past few years there has been a general decline in the prospecting, and no notable discoveries of new ore bodies or deposits that seem likely to give immediate material increase to the annual output of gold have been effected. The ore bodies in some of the large camps, as at Goldfield, already show a diminution in the value per ton of ore mined.

Imports and Exports.—According to estimates made for the Survey by the Bureau of Foreign and Domestic Commerce, the imports of gold for 1912 were valued at $61,400,000. The exports for the same year were valued at $48,600,000, The

excess of the imports over the exports for 1912 was $12,800,000 which forms a striking contrast with the conditions in 1909 when the exports exceeded the imports by $88,793,855. The imported gold in both ore and bullion came from Mexico, Canada, England, France, Central and South America. The exports consisted of refined bullion and coin and went largely to France, South America, Canada, and Japan with smaller shipments to the West Indies.

World's Production.—According to Frederick Hobart, the gold production of the world for 1912 exceeded that of any previous year. It was an increase of $10,000,000 or 2.2 per cent. over the output of 1911. The gain in the Transvaal alone was approximately $18,225,000. The mines of Rhodesia and West Africa also showed notable gains. The total African production was $211,789,000 while the Transvaal alone produced $188,285,000.

The Asiatic mines, especially those in the Kolar district in British India, increased their annual output. Australasia, which at one time produced nearly one-third of the world's total output of gold, now produces only 12.1 per cent. of the total. Western Australia is the largest producer in Australasia, The steady decrease in the value of the ore mined and the fact that no new gold-bearing ore bodies are being discovered are matters of moment in the consideration of the future of the industry. New Zealand also records a lessened production due to labor difficulties which it is expected will not materially affect the output of 1913. The decline in Russia was due also to labor difficulties and to the shortage of water in many of the important places, notably the Lena Gold Mining Company which in recent years has been the largest producer of Siberia. A decline was recorded also for Mexico which is attributed to the disturbed political condition of the country.

The total output of gold for 1912 was $469,618,083. There has been a steady annual increase in the production of gold for the last 14 years, save in 1910 when there was a decrease of approximately $5,000,000. Since 1893 the world's annual production of the yellow metal has increased $311,180,532.

SILVER

Price and Production.—The conditions surrounding the silver mining industry from 1908 to 1912 were not altogether satisfactory. The average price for silver in 1908 was 53 cents per

Troy ounce; in 1909 it was 52 cents; in 1910, 54 cents; in 1911, 53 cents; in 1912, it was 60.9 cents. While the lower prices for silver obtained, several large smelters in Utah and Colorado were partly closed or operated on a reduced capacity. This held especially true at Leadville where the ores are low grade.

The conditions operating against a large output of silver from 1908 to 1911 were: (1) The low price of silver for commercial purposes. (2) The low price of copper, lead and zinc with which silver ores are so often associated. (3) The failure of India to buy as much silver as usual, a condition that was partly offset by a larger purchase on the part of China. (4) The increased production in Canada due to the more recently discovered districts of Cobalt, South Lorrain and Gowganda.

The estimates of the United States Geological Survey and the Bureau of the Mint indicate a domestic silver production for 1912 of 62,369,974 fine ounces, valued at $37,982,414. This represents the largest annual output of silver for the last twenty years, although it does not represent the largest value of the period. The reports from the west indicate that when the statistics are finally completed the output will approximate 64,000,000 oz. If it reaches that figure it will represent the largest output in the history of the industry.

The conditions favoring this increase for 1912 were: (1) A higher price for the metal for commercial purposes; (2) a year of general business prosperity; (3) a liberal buying in all metals during the year; (4) large purchases of silver on the part of India and (5) a notable increase in the output of copper ores, especially those of Butte, Montana, which contain considerable silver, and of argentiferous lead ores, especially of the Tintic and Park City districts of Utah; the Pioche district of Nevada; the San Juan, Leadville and Aspen districts of Colorado. There was a small decrease in the output of the Coeur d'Alene mining district in Idaho due to lower grade of ore than formerly mined.

According to the *Mineral Resources of the United States* for 1911, Nevada was the first producer of silver with a value of $6,987,839 followed by Utah with a value of $6,611,107 and Montana with $6,352,154 . In 1912 the outputs in Troy ounces were as follows: Nevada, 13,042,118; Utah, 12,795,072; Montana, 12,338,589.

Imports and Exports.—According to estimates made by the Bureau of Foreign and Domestic Commerce the imports of silver

for 1912 were valued at $47,800,000. The exports for the same year were valued at $70,272,000, or $22,472,000 in excess of the imports. The imports were largely silver ore and bullion from Mexico and Canada. The exports were almost wholly in refined bullion and coin and went chiefly to the United Kingdom, although large amounts were shipped to France and China, with smaller amounts to British India.

World's Silver Production.—The silver production of the world in fine ounces for 1912 as given by the *Engineering and Mining Journal* is as follows:

Mexico	76,500,000
United States	62,369,903
Canada	35,250,000
Australasia	17,950,000
Other countries	37,500,000
Total	229,569,903

As will be seen in the table given above Mexico still holds the position of the first producer and the United States the second. By a comparison of these figures with those of 1911 it will be seen that the production of Mexico decreased approximately 3,000,000 oz., while that of the United States increased approximately 2,000,000. The remarkable increase during the past three years is in Canada where the production was more than 13,000,000 oz. greater in 1912 than in 1909. The one field giving rise to this condition is Cobalt where large supplies of silver ore have been opened in recent years. This field is somewhat augmented by outputs from the South Lorrain and Gowganda districts.

PLATINUM

Production.—Some platinum of recent years has been produced at the placer mines in Butte, Humboldt, Siskiyou, Trinity, Calaveras, Sacramento and Del Norte Counties, California, together with a small amount from western Oregon. Three-fourths of all the domestic platinum comes from Butte County.

The most noteworthy event in the platinum industry during the present century is the discovery of the comparatively new mineral sperrylite, the arsenide of platinum, $PtAs_2$, which occurs in the nickel-bearing ores of Sudbury, Ontario, and in the Rambler mine of Wyoming.

Importance is also attached to the discovery of platinum in association with several copper minerals, as covellite, the sulphide of copper, CuS. This result may lead to the discovery of platinum in other members of the copper group.

The average price paid for platinum in 1912 was $45.55 per Troy ounce as compared with $43.12 in 1911 and $32.70 in 1910. With this higher price for platinum it is rational to expect a persistent search for platinum ores in the placer gravels of serpentine rocks; in the members of the copper group, and in the nickeliferous pyrrhotites.

The demand for platinum is increasing faster than the supply. The newer requirements in the electrical and automobile-engine industries absorb the metal and remove it from the market entirely. The same is largely the case in the jewelry industry, while the metal used in making chemical ware is largely returned in the form of scrap platinum for manufacture.

The imports of platinum for 1912 were valued at $3,634,738. No platinum seems to have been re-exported.

Russia is the world's chief producer of platinum. The metal comes from the Siberian side of the Urals. The production for 1912 is estimated at 310,000 ounces. Colombia is the second producer with an output estimated at 12,000 ounces. A small amount of platinum is derived also from Canada, New South Wales, Borneo and Sumatra.

LEAD

Production.—The value of the output in the lead industry has risen from $23,280,200 in 1901 to $43,280,460 in 1912. The increment of increase has not been steady. In 1908 the production fell 32.56 per cent. below that of 1907. The lead produced in the United States is derived from various sources and receives different names, dependent upon its source.

Primary lead signifies lead that has been produced directly from its ores. *Secondary lead* is derived from scimmings, drosses, old metal, alloys, as babbitt, solder, and type metal. The recovery of lead by refining these materials constitutes an integral portion of the lead industry. The business is mostly carried on by the small refineries scattered over the United States, but the large smelters and refineries working primary lead frequently incorporate material from secondary sources.

Soft lead represents the production of the smelters in the Mississippi Valley where the ores are almost free from silver. Only one of the smelters in this district desilverizes its lead. However, a considerable quantity of soft lead ores have been annually smelted by various silver-lead smelters. A little soft lead ore is annually derived from Washington and other western states.

Refined lead embraces all of the desilverized lead produced in this country and the pig lead recovered from the Mississippi Valley lead industry.

Antimonial lead, or hard lead, is derived from the treatment of the gold and silver ores bearing antimony. The antimony combines with the lead as antimonial lead. The two metals are never separated, and there is a large demand for this product.

There are two lead pigments produced directly from various plumbiferous ores, namely, sublimed white lead and sublimed blue lead. The former consists of lead sulphate 75 per cent., lead oxide 20 per cent., and zinc oxide 15 per cent. The latter consists of lead sulphate varying from 50 to 53 per cent., lead oxide 41 to 38 per cent., together with small proportions of lead sulphide, lead sulphite, and zinc oxide. Zinc-lead oxide contains from 46 to 50 per cent. of lead sulphate, frem 32 to 46 per cent. of zinc oxide, and a small amount of zinc sulphate. Leaded zinc oxide varies from 4 to 20 per cent. in its lead sulphate content, while the remainder is zinc oxide together with a small proportion of zinc sulphate. The total lead content from domestic ores averages between 7000 and 8000 short tons.

Missouri is the first producer of lead followed by Idaho, Utah, and Colorado in the order of their importance. The United States produced approximately twice as much lead as any other country, followed by Spain, Germany and Mexico each of which produces more than 100,000 metric tons.

MERCURY

Production.—The unit of measure for mercury is different from that of the other metals. The liquid metal is put up in flasks. Each flask contains 75 lb. The market at San Francisco determines the price. The average price per flask for 1912 was $42.04. This represents a total value of $1,057,180 for the 1912 production.

According to H. D. McCaskey the gain of 3891 flasks over 1911 shows a larger increase than was generally expected, but he does not think it implies a corresponding increase in the output of 1913. A gradual decline in the output of some of the larger ore bodies and possibly unfavorable market conditions and prospects tend toward a reduction of the output.

The output of 1912 was the largest in California since 1905. The increase was due to two factors: (1) The satisfactory product of the New Guadalupe mine in Santa Clara county. (2) To increased output from several other mines. The New Idria mines in San Benito County are the largest producers in America and in fact produce nearly one-half of the California mercury. The output of these mines for 1912 was slightly less than in 1911 because attention was paid to development work rather than to increased production on account of low prices. Ore reserved for treatment when prices were at a higher level seemed preferable. Sixteen mines were producers for the year 1912 in California.

Texas is also a producer of mercury. According to W. B. Phillips there were no material changes in the industry during the year 1912. The Chisos Mining Company carried their explorations into the Buda limestone that underlies the Eagle Ford shales and found about the same quality of ore as in the overlying bituminous shales. A furnace has been constructed on the property to handle a larger tonnage of lower grade ore rather than a smaller tonnage of high grade ore. In the Terlingua district the larger percentage of the ore has come from the hard, dense limestone of the Edwards formation which has yielded ore of extreme richness at comparatively shallow depths. It is Phillips' belief that the future of the mercury industry in Texas will be more intimately connected with the bituminous shales than with the associated limestones.

BISMUTH

Production.—The production of metallic bismuth in the United States is very small. The years 1902, 1903, 1907, report no output whatever. The United States Metals Refining Company produces a small amount of bismuth as a by-product at its electrolytic lead refinery at Grasselli, Indiana. The bismuth is obtained in the anode muds of lead bullion. The most of the

bismuth-bearing ores come from the Tintic district, Utah, and are smelted at Bingham Junction.

Many tungsten ores are bismuth bearing. The latter metal may be recovered as a by-product when reducing the tungsten. Some bismuth is recoverable in the electrolytic copper refineries.

According to F. L. Hess in 1911 one lot of bismuth-bearing ore was produced at the Comstock mine, La Plata, La Plata County, Colorado. This ore contains from 6 to 8 per cent. of bismuth but was sold for its gold and silver content. A smaller amount of higher grade bismuth ore was mined near Tularosa, New Mexico.

The average price for metallic bismuth for the year was $1.72 per pound. The value of imported bismuth for several years has been between $300,000 and $400,000. The larger part of the supply of the crude metal comes from Bolivia, where the Aramayo Francke Mines, Ltd., is one of the large producers. The crude metal is shipped to Europe for subsequent refining. According to the *Engineering and Mining Journal* there will be one new producer of bismuth in 1913, viz., The American Smelting and Refining Company which has completed its plant at Omaha, Nebraska.

COPPER

Production.—The production of copper in the United States shows a steady increase. The only large reduction in any single year came in 1907 as a result of the general financial depression. The output of copper for 1912 is the largest ever recorded. The copper-producing states, Arizona, Michigan, Utah, Colorado, New Mexico, and Alaska, each exceeded all former records. Montana and Tennessee nearly equalled their banner output.

There is no close competitor to the United States in the production of the red metal. In fact the United States produces more than 50 per cent. of the world's supply of copper. The increased output is due to several causes. (1) The discovery and the opening of many new mines. (2) The working of old mines to their full capacity. (3) The extension of electrical works of all kinds. (4) The construction of new electrical roads. (5) The substitution of electricity on existing roads. (6) The present period of high and profitable prices.

According to B. S. Butler of the U. S. Geological Survey the output of blister and Lake copper for 1912 was 1,249,000,000 lb., which at an average price of 16 cents per pound amounts to approximately $200,000,000. The figures of the Copper Producers' Association indicate a production of refined copper from all sources, domestic and foreign, of approximately 1,500,000,000 lb. for 1912.

The average price for electrolytic copper for 1912 was highly satisfactory, averaging about 16 cents as compared with 12.5 cents per pound in 1911.

According to the Bureau of Statistics the imports of copper for 1912 approximated to 404,721,323 lb., which is 70,000,000 lb. in excess of the importation of 1911. The metal is imported in the forms of old copper, pigs, bars, ingots, plates, etc. The exports for 1912 were approximately 750,000,000 lb.

Arizona holds the rank of the first producer. The state also holds the enviable record of furnishing a larger production than that ever recorded by any state for a single year. The output approximated 350,000,000 lb., and came largely from the Bisbee, Morenci-Metcalf, and Globe-Miami districts.

Montana was the second producer with an output exceeding 300,000,000 lb. As in previous years the output came largely from the Butte district. Michigan ranks third as a copper producer. The product came largely from the old producers stimulated by the high prices for the metal. Utah, Nevada, California, New Mexico and Alaska are noteworthy producers. The output in Alaska came largely from the Copper River and Prince William Sound districts although southeastern Alaska contributed somewhat to the supply.

The total output of copper for the world for 1912, as estimated by the *Engineering and Mining Journal,* was 1,004,844 metric tons. Of this amount the United States produced 536,747 tons, Mexico 71,982 tons, Spain and Portugal 58,000 and Japan 54,000.

CADMIUM

Production.—The output of cadmium in the United States is small, due to the fact that its chief ore is limited in quantity and distribution, and also to the limited demand for the metal.

According to C. E. Siebenthal, metallic cadmium has been

recovered in the United States since 1907 by only one company until the latter part of 1910. Since that time there have been two producers. A small quantity of the pigment, cadmium sulphide, is also produced. The metal may be derived: (1) From the fractional distillation of zinc ores; (2) recovered as a by-product in the manufacture of lithopone; and (3) by the dry distillation or electrolysis of the slimes formed in the manufacture of zinc chloride.

The chief output of cadmium comes from the zinc-producing districts of Silesia, where the metal is recovered as a by-product in the manufacture of zinc. In England a small amount of cadmium has been recovered in the purification of the solution of zinc sulphate in the manufacture of lithopone.

A small amount of metallic cadmium is annually imported in the form of sticks. Also a small amount of the sulphide under the name of cadmium yellow. The total average value of these products is less than $5000 per annum.

ARSENIC

There was no production of white arsenic in the United States prior to 1901. Among the new industries that have been developed recently is the manufacture of white arsenic as a by-product in the treatment of other ores. A pioneer in this industry was the Puget Sound Reduction Company which recovered arsenic from the Monte Cristo, Washington, ores. The Everett smeltery at Everett, Washington, the Washoe plant at Anaconda, Montana, and the United Smelting Company at Midvale, Utah, are among the producers of this commodity.

The production suffered a decline in 1904, 1909, and in 1912. The output for 1912 was 5,852,000 lb. in comparison with 6,162,000 lb. in 1911.

The imports of arsenic are not heavy. About 150 tons of red arsenic, As_2S_2, and from 50 to 75 tons of metallic arsenic and lead-arsenic alloys meet the demand for these products. Germany, France, United Kingdom, Spain, in the order of their output, produce a total of between 2000 and 3000 metric tons of white arsenic per annum.

ANTIMONY

Antimony for consumption in the United States is largely derived from four sources: (1) Hard lead obtained in the

smelting of foreign and domestic ores; (2) imported regulus or metal; (3) imported antimony ores; and (4) domestic ores. According to the *Engineering and Mining Journal* several carloads of ore were mined in 1912 in Utah, and successfully treated to recover the antimony content, but even at the present price of the metal, the mines are burdened with too expensive transportation to be profitable, and they have suspended production. The bulk of antimony used in the United States must therefore be imported. The duty on the crude metal is 1½ cents per pound and 1 cent per pound on the metal in ore.

The average price for metallic antimony in 1912 was 8.26 cents per pound. The imports of antimony in all forms for the first 10 months of the year were 8,848,874 lb., which was an increase of 355,370 lb. over 1911. The antimony oxide produced during the year was practically all manufactured from Chinese needle antimony.

TIN

The production of tin in the United States is a matter of perennial interest because of the peculiar deficiency of tin deposits and the large domestic consumption. The chief interest surrounding the tin industry during the present century lies in the construction of a mill and smelter for the production of the metal by the El Paso Tin Mining and Smelting Company in Texas. (2) The Pahasa Mining Company has opened the old shaft of the Harney Peak Tin Company of the Southern Black Hills in South Dakota, and sampled the ore bodies to ascertain their value. (3) The increasing output of tin in Alaska.

The tin for domestic consumption comes from three sources: (1) domestic primary tin, (2) secondary tin, (3) imports.

According to F. L. Hess the output of tin in Alaska for 1911 was 61 tons of metallic tin valued at $52,409. The vast majority of this came from the placers on Buck Creek. A small amount came from the placers of Tofty Gulch, on Sullivan Creek, between Fairbanks and the mouth of Tanana River. The tin mine near El Paso, Texas, produced 5 tons of metallic tin. The entire output of the United States for 1911 was values at $56,635.

According to J. P. Dunlop the secondary recoveries of tin form the most important domestic source of supply. Tin is recovered from the various alloys containing the metal as

babbitt, bronze, solder, etc. It includes the tin content of products made by several plants from tin scrap as tin oxide, putty powders, but mainly tin chloride. The largest recovery of tin is made from the scruff and drosses that are formed in the manufacture of tin and terne plate. Practically no clean scrap tin plate is wasted. A large quantity of tin is recovered in the form of tin powder by electrolytic treatment. Lesser sources of tin are tin foil, block-tin pipe, and old tin cans. The amount of secondary tin recovered from all sources in 1911 was valued at $12,353,040.

The total value of the imports of tin for 1911 amounted to $43,584,219, which exceeds the value of the importation for any other year.

The Federated Malay States produces more tin than all the other countries of the world combined. The order of the states in the production is as follows: Perak, Selangor, Negri Sembilan, and Pahang. Bolivia is the second producer and Banka the third. The shipments from Banka are to Holland. The output of Cornwall, England, is about 5000 short tons per annum.

IRON

According to E. F. Burchard of the United States Geological Survey the production of iron ores for 1912 was between 54,500,000 and 57,500,000 tons. The quantity represents an increase of approximately 30 per cent. over the output of 1911 which was 43,550,633 tons. A high record in the output of iron ores was established in 1910. When it aggregated 56,889,734 long tons.

The percentage of red and specular hematite mined year after year is increasing. More than 90 per cent. of the iron ore mined for 1912 came from these two varieties of hematite. Limonite and magnetite in about equal proportions contributed the remainder save for a very small percentage of siderite. This mineral ordinarily contributes in America about 0.1 per cent.

The Lake Superior district produces more than 80 per cent. iron ore. These ores not only supply the furnaces of the Central West but also find their way east of the Atlantic Coast.

The production of the Birmingham district in Alabama was also largely increased in 1912. For this increase the Clinton hematite of the Red Mountain group was largely responsible.

The production of Tennesee, North Carolina and Virginia remained about the same as in 1911.

The heavy demand for iron ores in 1912 increased mining activities in New York, New Jersey, and Pennsylvania. In these states several new mines were opened, some old mines were reopened, and some improvements were made in the concentration of the ore to make it more available for the furnaces. The largest activity was in the Champlain district in the vicinity of Port Henry, Mineville and Dannemora.

Imports and Exports.—The imports of iron ore for the first ten months of 1912 were 1,741,607 tons. Of this amount more than 1,000,000 tons came from Cuba. Other contributors in the order of their importance are Sweden, Newfoundland, Canada, Spain, and Venezuela. The exports of iron ore for the same period exceeded 1,000,000 tons. The ores were mainly derived from the Lake Superior district and were shipped to Canadian furnaces.

The Bureau of Statistics gives the value of the exports of iron ore for the 10 months ending Oct. 31 as $238,972,631 as compared with imports for the same period of $23,885,776.

Pig Iron.—According to the *Engineering and Mining Journal* the production the pig iron in 1912 aggregated 29,647,274 tons, thereby surpassing the production of 1910, and nearly equalling that of 1909.

The production is classified as follows:

Bessemer	11,740,055
Basic	11,386,176
Foundry and forge	5,965,591
Charcoal	353,266
Spiegel and ferro	202,186
Total	29,647,274

The pig iron industry in the United States during the present century has suffered three reverses due to disturbed financial conditions. The first came in 1904 in which the reduction was approximately 2,000,000 tons. The second came in 1908 with a reduction of approximately 10,000,000 tons. The third came in 1911 with a reduction of approximately 3,500,000 tons.

Germany stands next to the United States in the production of both pig iron and steel. The amount approximates 13,000,000 tons of each commodity. The United Kingdom ranks third

in the list. The output of pig iron approximates 10,000,000 metric tons, and of steel 6,000,000 tons.

The United States produces nearly one-half of both the pig iron and steel of the world. The three great nations, the United States, Germany, and the United Kingdom produce approximately four-fifths of the world's supply of these two most important commodities.

ALUMINUM

The increase in the magnitude of the aluminum industry in the United States is reflected by the fact that in 1883 the production was only 83 lb. and in 1911 it was 46,125,000 lb. In 1912 there was no substantial increase in the production of the metal nor any substantial change in the general manufacturing conditions. The Aluminum Company of America is at present the chief manufacturer of the metal in the United States.

There were no radically new uses for the metal developed during the year. There was marketed a new electrical conductor composed of seven wires. The center wire was steel of high tensile strength. This type of cable supplies a conductor that is both light and strong for long distance transmission work.

A minor new use for the metal lies in the manufacture of aluminum foil which is displacing tin foil as a wrapper for candy and tobacco.

CHROME IRON ORE

According to W. C. Phalen the production of chrome iron ore in 1911 was only 120 long tons valued at $1629. This, however, represents the amount actually sold. It is a reduction of almost 50 per cent. in both tonnage and value from that of 1910.

The chrome iron industry has been fluctuating and is declining. Prices have had a downward trend. This fact seems a little strange in the light of the quotations for tungsten and vanadium ores as ingredients in special steel alloys, one of the most important uses of a chromium. One reason for the decline lies in the wide distribution of chromite and the pockety character of known deposits free from impurities.

The chrome iron ore of recent years has been produced mainly in New Caledonia, Asia Minor, Greece, Canada, India, Rhodesia,

and Japan. The supply in New Caledonia is the best known but this also fluctuates in the amount and value of its production. In 1906 the production of this single field was 84,241 metric tons, but in 1907 it fell to 3800 metric tons. The output of Russia where the industry centers in the Urals, and in India in Baluchistan and Mysore, the industry is subject to the same fluctuations. The output of Rhodesia which is the foremost producer at present is increasing. The mines are not far from Selukwe, about 560 miles from the port of Beira. The production from Rhodesia shows that ores from deposits in a comparatively inaccessible part of the world may be placed upon the European market under conditions which enable them to compete with more favorably situated supplies.

COBALT

According to F. L. Hess there was no production of cobalt in the United States in 1911. A possible source of cobalt lies in the concentrates saved in extracting lead ores at Fredericktown and Mine La Motte, Missouri. A second possible source when transportation facilities are improved is near Blackbird, Idaho. The supply of cobalt for domestic consumption is said to come wholly from Cobalt, Ontario. The ores are shipped to England and the oxide imported. Cobaltiferous ores from which the oxide is also manufactured are treated by the Orford Copper Company, Constable Hook, N. Y.

The interesting alloy stellite, composed of cobalt and chromium, is manufactured on a small scale for knives with stellite blades. This use appears to hold the most promising outlook for the metal.

NICKEL

A small amount of nickel, amounting approximately to $125,000 is saved as a by-product from the electrolytes of the copper refineries. Much of the copper refined electrolytically contains small percentages of nickel which during the process of refining the copper passes into the electrolyte. If the accumulation exceeds 1 per cent. it is said to be harmful to the perfect deposition of the copper. The copper thus treated comes from domestic and foreign sources, but the amount derived from

each source is unknown. All other nickel used for domestic consumption comes from Sudbury, Ontario.

In the Sudbury district nickel mining was active during 1912 and the production, the largest on record, approximately 21,000 tons. The Canadian Copper Company by a series of testing in the Frood mine is said to have proven in this mine alone the existence of 10,000,000 tons of ore.

The Mond Nickel Company carried on development work on an extension of the Frood ore body. The Alexo mine in Dundonald township shipped several thousand tons of good ore during the latter part of 1912 to the Mond Nickel Company's smeltery at Victoria Mines.

The Dominion Nickel-Copper Company by a similar series of drill testings has proven the existence of about 6,000,000 tons of ore about one-fourth mile west of the old Murray mine.

The imports of nickel average about $4,000,000 while the exports of nickel, nickel oxide, and matte surpass $8,000,000.

MANGANESE

The managanese industry in the United States depends largely upon the activities in the pig iron and steel industries. With the increased production of pig iron during the last two years there has been a greater demand for managnese ores. The production, however, has been small, averaging about 2,500 tons per year valued approximately at $25,000. Virginia and California are the principal producers. The value of the imports of managnese ores for domestic consumption exceeds $1,000,000.

The annual domestic production of manganiferous ores exceeds 500,000 long tons. The Lake Superior region produced over 91 per cent. of the tonnage. The ore averages less than 6 per cent. of manganese and is used a source of high-manganese pig iron. The manganese ores of Colorado, which is the second state in rank in this industry, are used for fluxing. These ores are also argentiferous. The manganiferous ores of Batesville, Arkansas, are utilized in the manufacture of high-manganese pig iron in the blast furnaces at St. Louis, Missouri.

The production of manganese-zinc residuum from New Jersey zinc ores has averaged more than 100,000 long tons per annum. These ores consist of franklinite, zincite, and willemite. In

the roasting process most of the zinc is removed, and the residuum consists largely of manganese and iron oxides. These are used for the manufacture of ferromanganese and spiegeleisen. The largest value for this product was recorded in 1908, viz., $423,792.

The manganese deposits of the Caucasus are among the richest in the world. The principal mines are at Tchiatouri in the Government of Kotais, about 126 miles from the ports of Batum and Poti on the Black Sea. England, Germany, and the United States are the largest purchasers. Smaller quantities are shipped to France and Belgium. The total exports from these shipping points during the last few years has averaged approximately 500,000 tons.

Manganese ores are mined in widely separated districts in India. The production now approximates 1,000,000 metric tons per annum. Some of the manganese mines in the State of Minas Geraes, Brazil, have been worked since 1894, with an annual production of about 60,000 tons. In the States of Bahia and Matto Grosso manganese ores are also mined. The Brazillian ores are estimated as sufficient to supply the world's requirements for several centuries.

ZINC

The principal source of zinc ores for 1912 came from the Joplin district in Missouri, the Wisconsin district, Leadville, Colorado, and Butte, Montana. According to C. E. Siebenthal of the United States Geological Survey the zinc industry for 1912, stimulated by the prevailing high price of spelter, went far beyond all preceding records in the production of spelter. The production of primary spelter from domestic ores was 323,961 short tons and from foreign ores 14,669 tons making a total aggregate of 338,630 tons. The value of this banner production is estimated at $46,731,000 which is an increase of more than $12,000,000 over the value of the production for 1911.

The imports of zinc ore for 1912 were approximately 78,000 short tons, containing about 31,500 tons of zinc. This excludes 18,245 tons of lead ore from South America which contained 2,431 tons of zinc. This amount was not recovered in the smelting of the lead.

The imports of spelter for 1912 were the largest for many years. The amount is estimated at 10,700 short tons and the value at $1,202,000.

The exports of domestic zinc ores were 19,953 short tons and the export of zinc dross for the same year amounted to 203 short tons.

The average price of spelter at St. Louis, Missouri, was 6.9 cents per pound as compared with 5.7 cents for 1911.

The United States ranks first as a producer of spelter and is closely followed by Germany and Belgium. The world's production of spelter in 1912 was 956,335 metric tons.

MOLYBDENUM

There is annually a small production of molybdenum ore in the United States. The Primos Chemical Company of Primos, Pennsylvania, is the chief manufacturer of molydenum and ferro-molybdenum in this country.

The price of the metal in 1912 was $1.40 per pound and of the alloy about $1.60 per pound of its molybdenum content.

The metallurgical requirement for molybdenite is 92 per cent. molybdenum sulphide. The value of such ore is approximately $400 per ton. To maintain this value the ore must be reasonably free from copper as the latter is an objectionable impurity.

Lower grade molybdenite ores are valued at about $1 per unit. This holds especially true if the ore concentrates to 25 per cent. molybdenum sulphide. Wulfenite which contains 25 per cent. of molybdic trioxide, MoO_3, is worth about $100 per ton.

TUNGSTEN

According to F. L. Hess of the United States Geological Survey the amount of tungsten ores mined and marketed in the United States in 1912 was 1290 tons carrying 60 per cent. tungsten trioxide, WO_3. The value of this product was estimated at $492,000. It was a substantial increase over the output of 1911. The average price per unit was $6.35. The unit is 1 per cent. of a short ton of tungsten trioxide.

The largest production of any single district came from the unique ferberite deposits of Boulder County, Colorado. About 1200 tons of ore was shipped from this district. The Primos Mining and Milling Company and the Wolf Tongue Mining Company are the largest producers.

In California the Atolia Mining Company, which controls the Atolia field at the north edge of San Bernadino County, increased its production of scheelite. This company is the largest individual producer of tungsten ores in the United States.

A new discovery of scheelite was reported from the west side of Rand Mountains but no ore was sold during 1912. A few tons of mixed scheelite and wolframite were shipped from the vicinity of Nipton in the east end of San Bernadino County.

In Arizona a few tons of hübnerite were shipped from the dry placers and some ore from the veins near Dragoon. Hübnerite was shipped also from Arivaca and scheelite from Oracle. Other small shipments were made from Nevada, Idaho, Washington, and New Mexico.

URANIUM

The production of uranium oxide for 1912 has been estimated by F. L. Hess as 26 short tons. This would represent approximately 20 tons of metallic uranium. This was a slight increase over the production of 1911.

The uraniferous ores were all carnotite, a variable compound of uranium and vanadium, from the Jura-Trias formations of the high plateau region of Colorado and Utah. The largest and richest deposits are found in Montrose County, Colorado, in Paradox Valley, Long Park, and the McIntyre districts. In Utah the carnotite came from Emery and Grand Counties.

A small amount of uraninite was mined near Central City, Gilpin county, Colorado, and sold as laboratory material. A few pounds partly altered to gummite were mined near Penland, North Carolina.

VANADIUM

The larger part of the vanadium ore mined in the United States in 1912 was a sage-green vanadiferous sandstone which contains the vanadium mica, roscoelite. It was mined near Newmire, San Miguel County, Colorado. The vanadium was obtained in the form of an iron vanadate at the local reduction plant of the Primos Chemical Company. The iron vanadate was shipped east to be smelted into ferro-vanadium. The price of metallic vanadium in former years has been from $4 to $5 per pound

but in 1912 it fell to \$2.50 and \$2 for the vanadium contained in ferro-vanadium.

The imports of roasted patronite, a vanadium sulphide, from Peru, were large and the production of ferro-vanadium probably the largest in the history of the industry.

TITANIUM

According to F. L. Hess there was only one American producer of rutile in 1912. This was the American Rutile Company whose mine and mill are located at Roseland, Nelson County, Virginia. This company produced in 1912, 275 tons of concentrates carrying from 80 to 85 per cent. TiO_2. The principal impurity is an iron oxide in ilmenite. The ilmenite is separated from the rutile by an electro magnet. About 100 tons of concentrates were produced in 1912, containing 94 per cent. of TiO_2. The separated material carries from 50 to 60 per cent. of titanic oxide and 42.3 per cent. of iron oxide. The prices ranged from \$30 to \$100 per ton according to percentages of TiO_2 and the quantity of the concentrates placed at one time.

ZIRCONIUM

The production of zirconium in the United States is limited to a few thousand pounds per annum. In 1910 there was no output recorded. The product is generally derived from the monazite sands of North Carolina. Another interesting locality is Baringer Hill, Texas. This locality is 12 miles north of Kingsland, the nearest railroad station.

The economic interest in the rare earth minerals centers in their incandescence when heated. Thoria, beryllia, yttria, and zirconia show this property in the largest degree. Thoria and beryllia form the bulk of the incandescent oxides used in gas mantles. They are too easily volatilized to be used in an electric glower, such as the Nernst lamp. Zirconia and yttria will stand the necessary high temperature.

According to the January-March, 1913, Bulletin of the Imperial Institute the largest use of zirconia lies in its employment as a refractory material. Crucibles moulded from a mixture of 90 parts of zirconia and 10 parts of magnesia made into a paste with 10 per cent. of phosphoric acid are extremely resistant to

heat and practically unaffected by molten alkalis and strong acids. Starch is sometimes used as a binder. The crucibles are dried for several days and fired in a Hempel electric furnace at a temperature of 2000 to 3000° C.

Owing to the low coefficient of expansion of zirconia these wares can be plunged red-hot into water without risk of fracture.

A small amount of zirconium is manufactured into ferro-zirconium which is used in the refining of steel.

COLUMBIUM

The production of columbite in the United States is limited to the mining of a few hundred pounds annually for museum and laboratory material. Such a production was produced in 1911 by E. E. Hesnard, Custer, South Dakota.

TANTALUM

The production of tantalum in the United States is likewise small. It is derived largely for domestic consumption from the mineral tantalite. The one use which has brought tantalum into prominence has been the making of filaments for incandescent electric lamps. The toughness of the metal made its use popular. Within the last few years the process by which tungsten wires can be drawn has been so far improved that tantalum lamps can show little advantage in toughness over tungsten lamps.

As wire for incandescent electric lamps tantalum is valued at approximately $500 per avoirdupois pound.

A small quantity of tantalum is annually imported.

SELENIUM

The production of selenium in the United States is not large. It now averages about 10,000 lb. The product is obtained as a by-product in the electrolytic refining of copper. The price ranges from $3 to $5 per pound. Selenium is used in the manufacture of enamels, glazes and red glass.

TELLURIUM

The actual production of tellurium in the United States is small. It can be recovered in considerable quantities in the elec-

trolytic refining of copper. It is abundant in the Cripple Creek, Colorado, district as the mineral calaverite. It occurs also in the gold ores of the Camp Bird and Torpedo-Eclipse Mining Companies in the San Juan district. In the Cripple Creek district alone more than 500 tons of tellurium has become a waste product. No practical use is known for the element and therefore there is no market. It is known however that in certain experiments the element has shown a peculiar behavior toward electricity which seems to indicate that electrical uses may yet be found for tellurium.

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